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**Kremerman et al.**

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(54) **SUBSTRATE PROCESSING SYSTEMS AND  
ROBOT APPARATUS FOR TRANSPORTING  
SUBSTRATES IN ELECTRONIC DEVICE  
MANUFACTURING**

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**Y10S 901/15** (2013.01); **Y10T 74/20305**  
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See application file for complete search history.

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**B25J 9/10** (2006.01)

**H01L 21/677** (2006.01)

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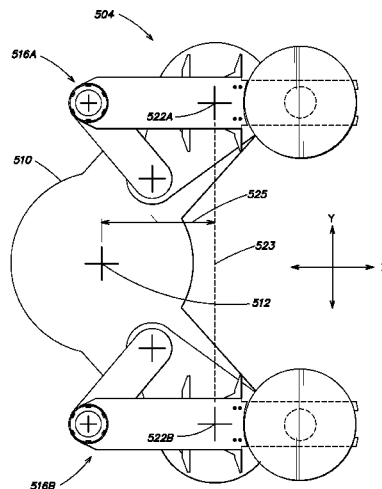
**ABSTRACT**

Robot apparatus, substrate transport systems, and methods  
are described. The robot apparatus and systems are adapted  
to efficiently put or pick substrates at a destination by  
rotating a boom linkage to a position adjacent to the desti-  
nation and then actuating robot assemblies to put or pick the  
substrates at the destination. Numerous other aspects are  
provided.

(52) **U.S. Cl.**

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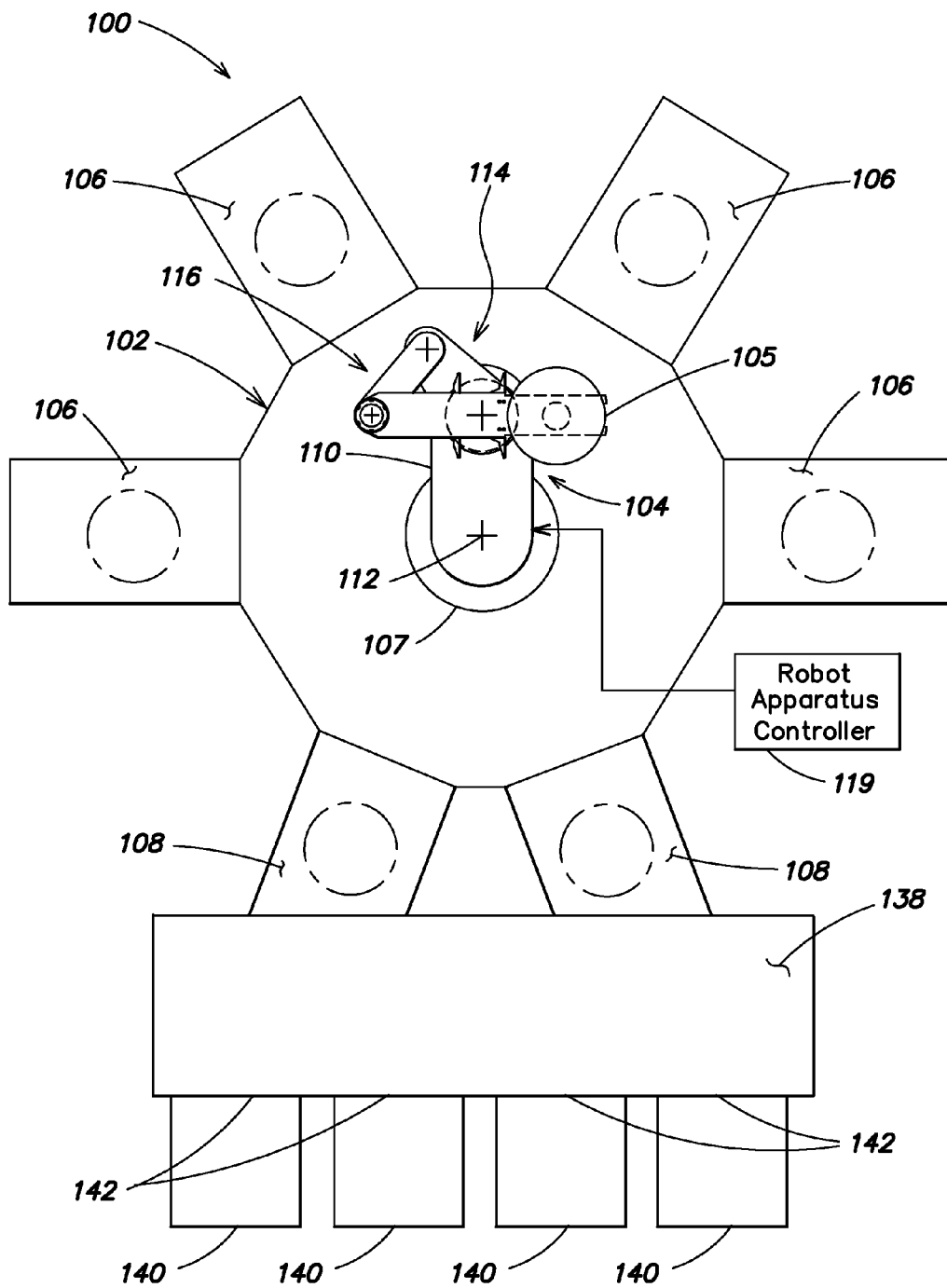
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**FIG. 1**

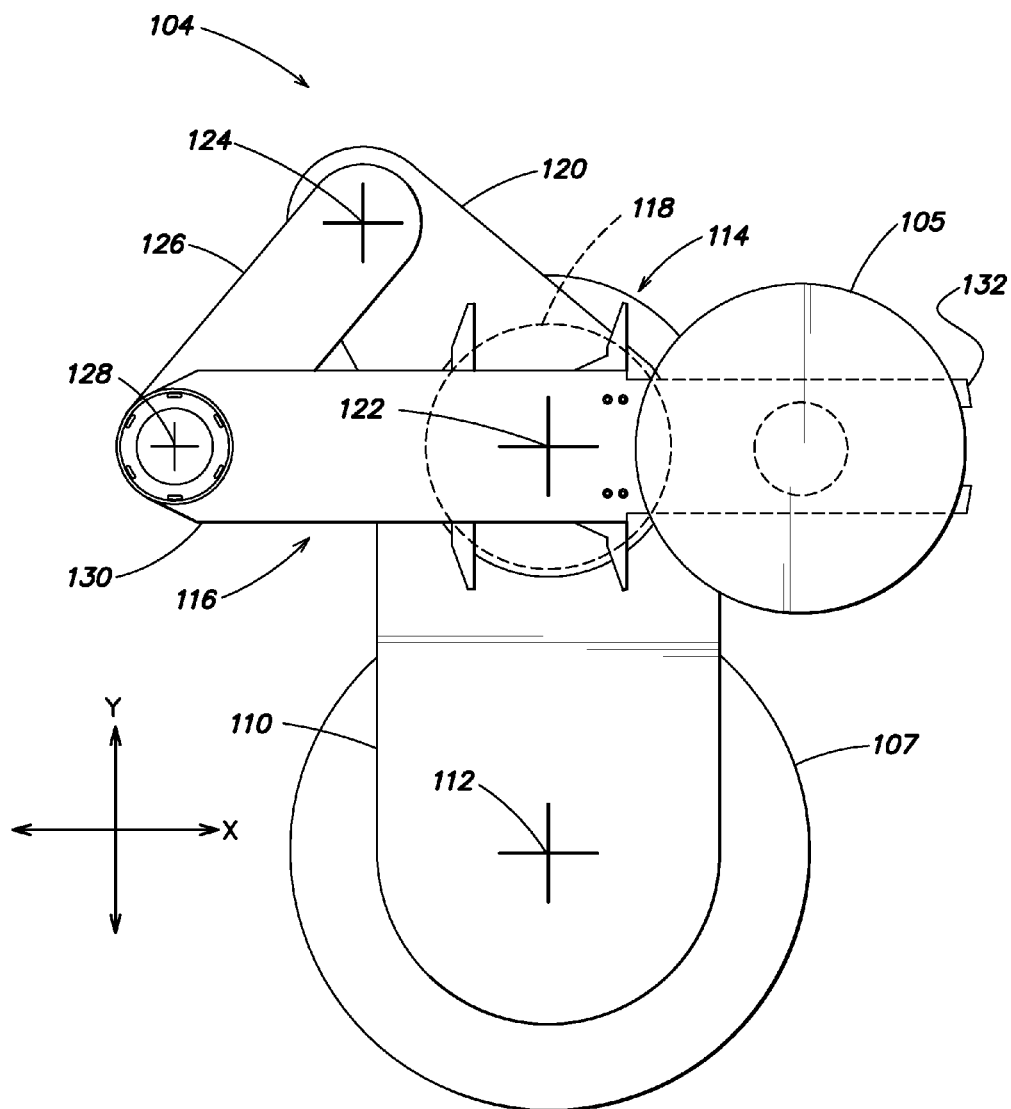
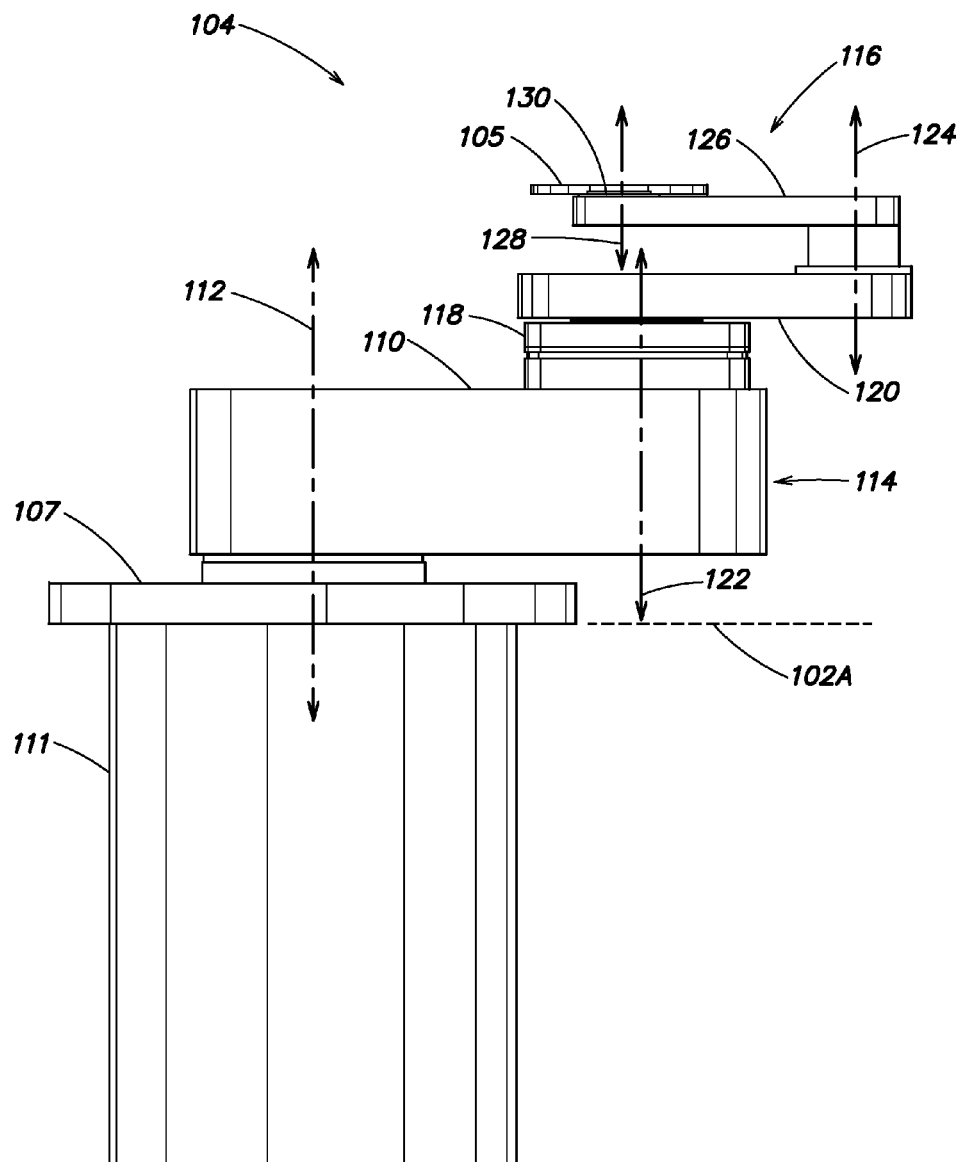


FIG. 2A



**FIG. 2B**

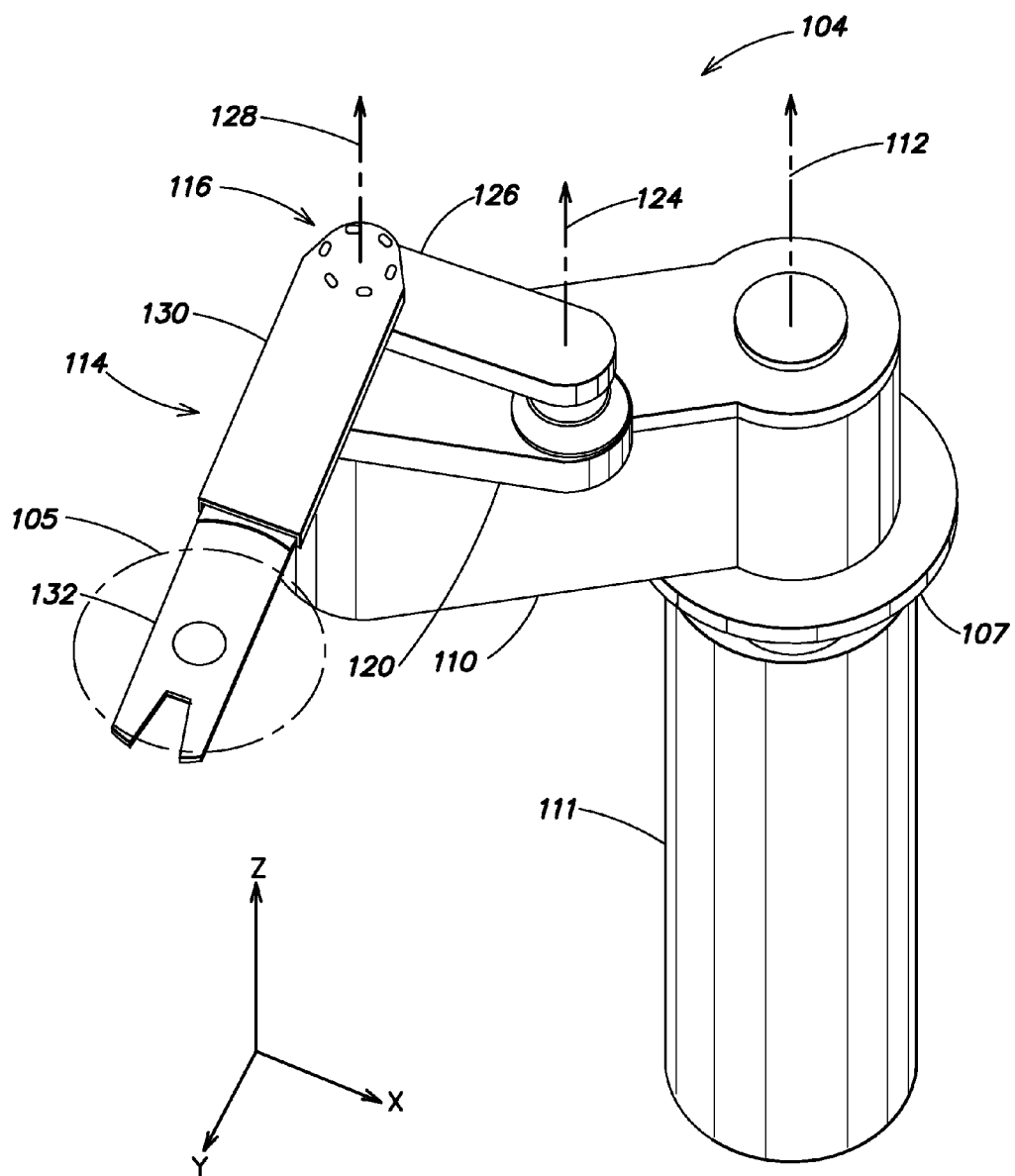
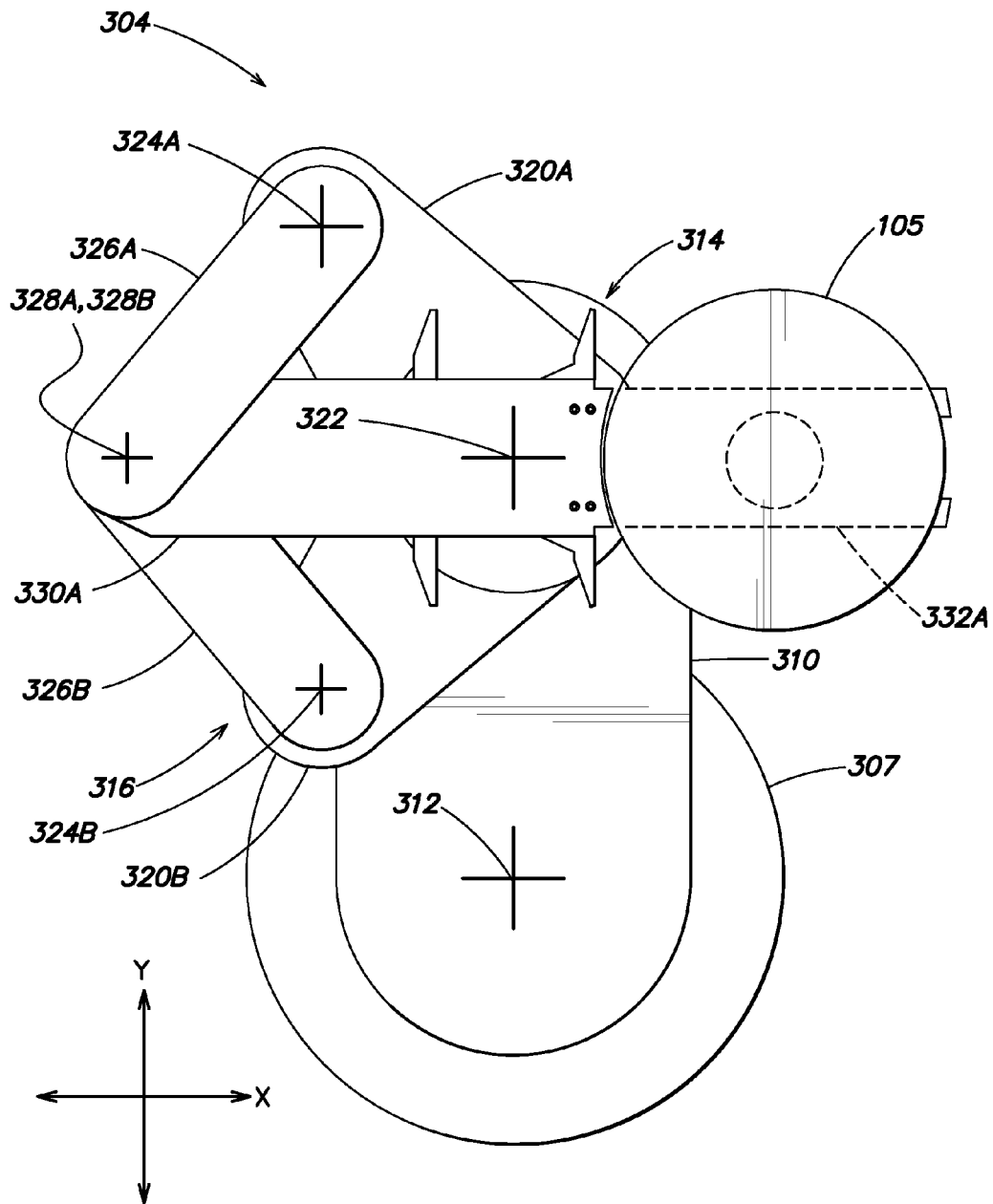


FIG. 2C



**FIG. 3A**

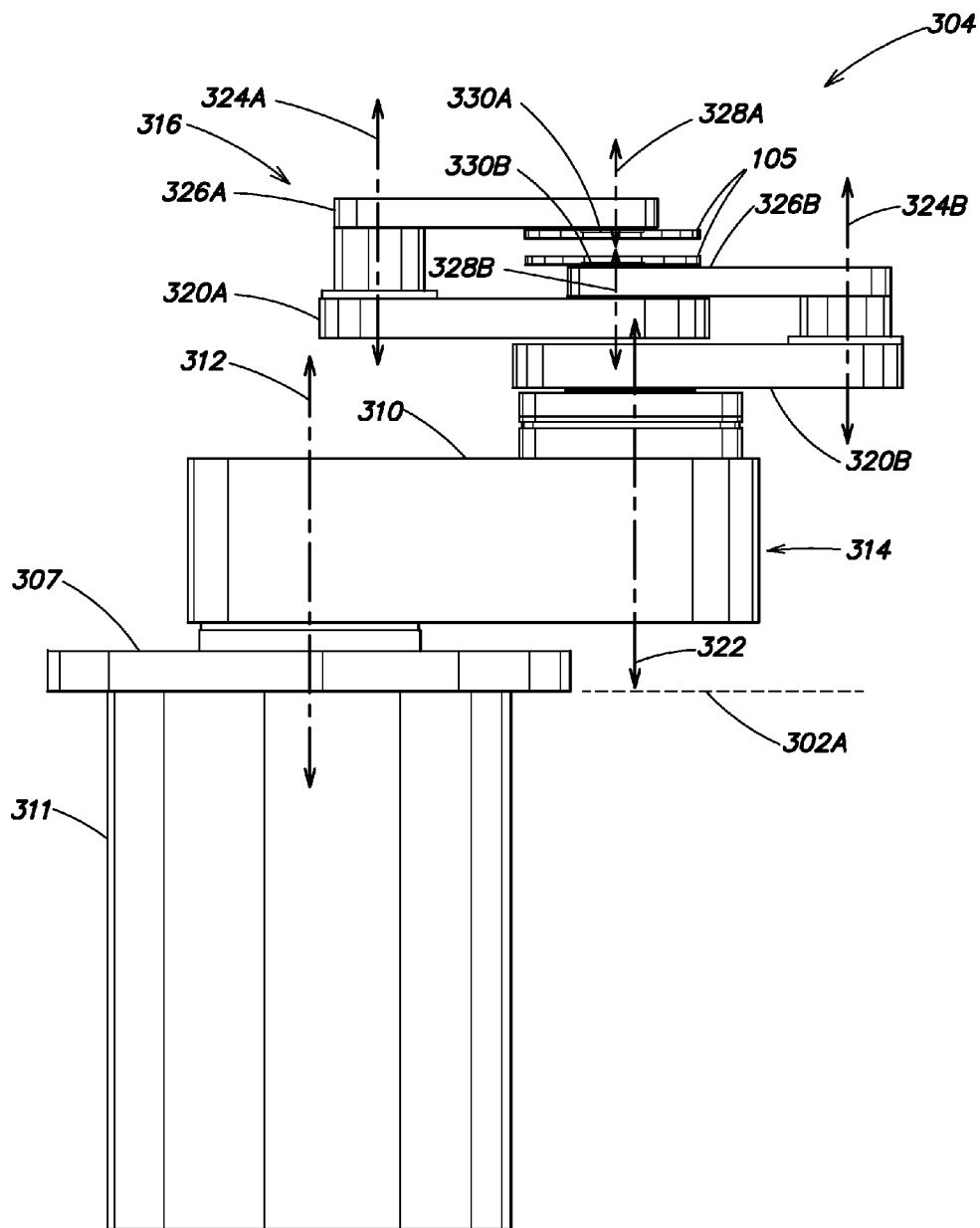
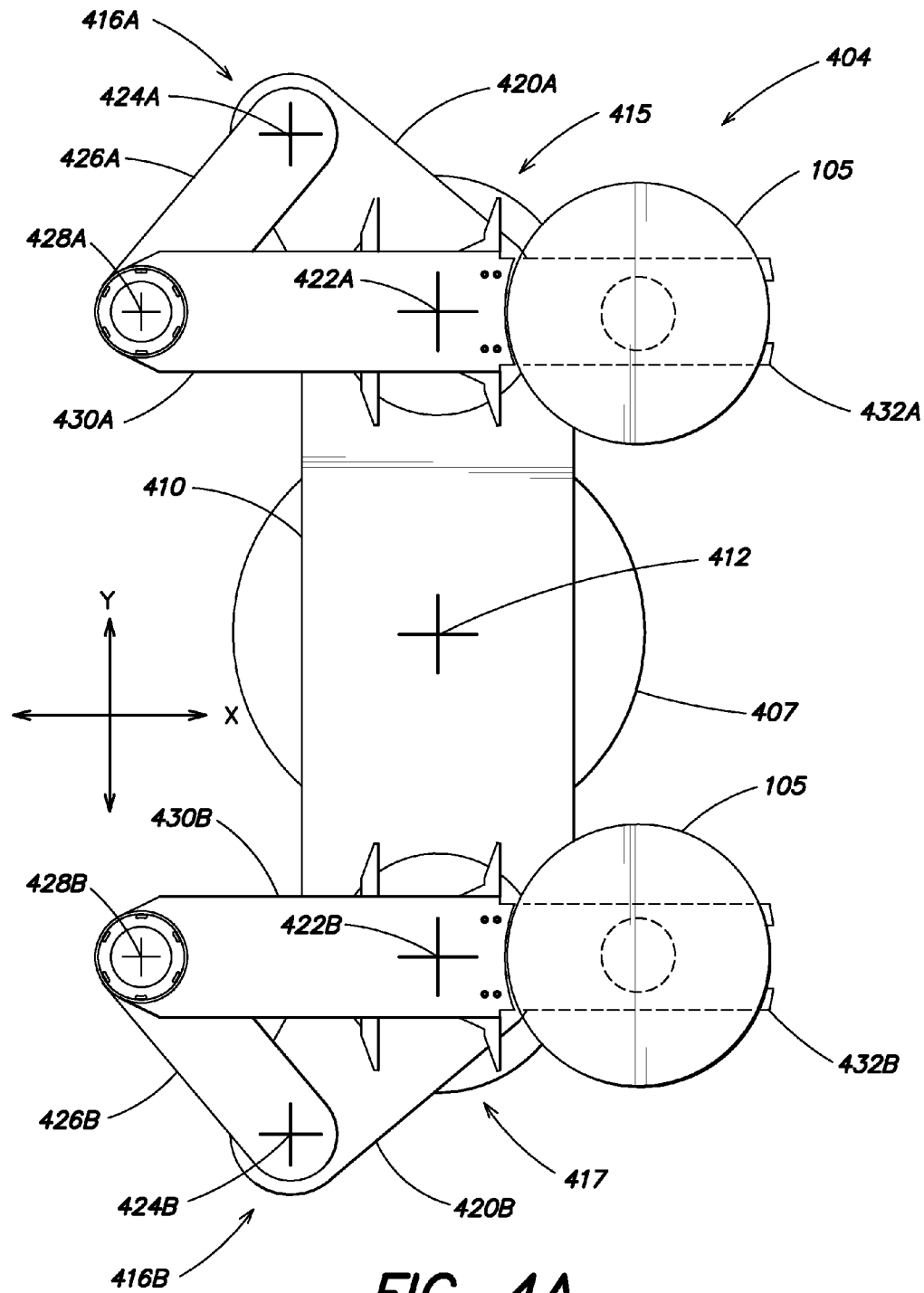
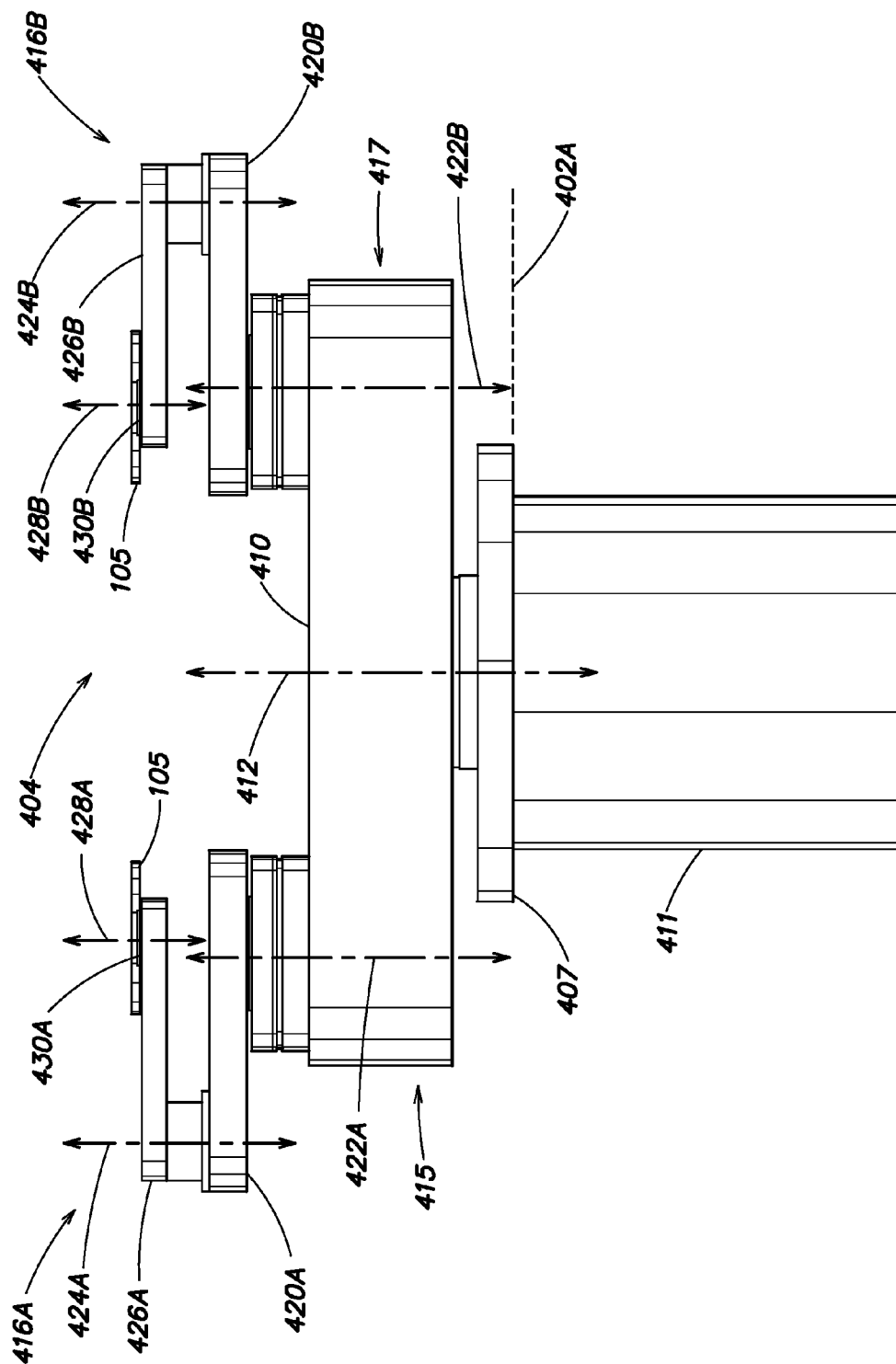


FIG. 3B



**FIG. 3C**





**FIG. 4B**

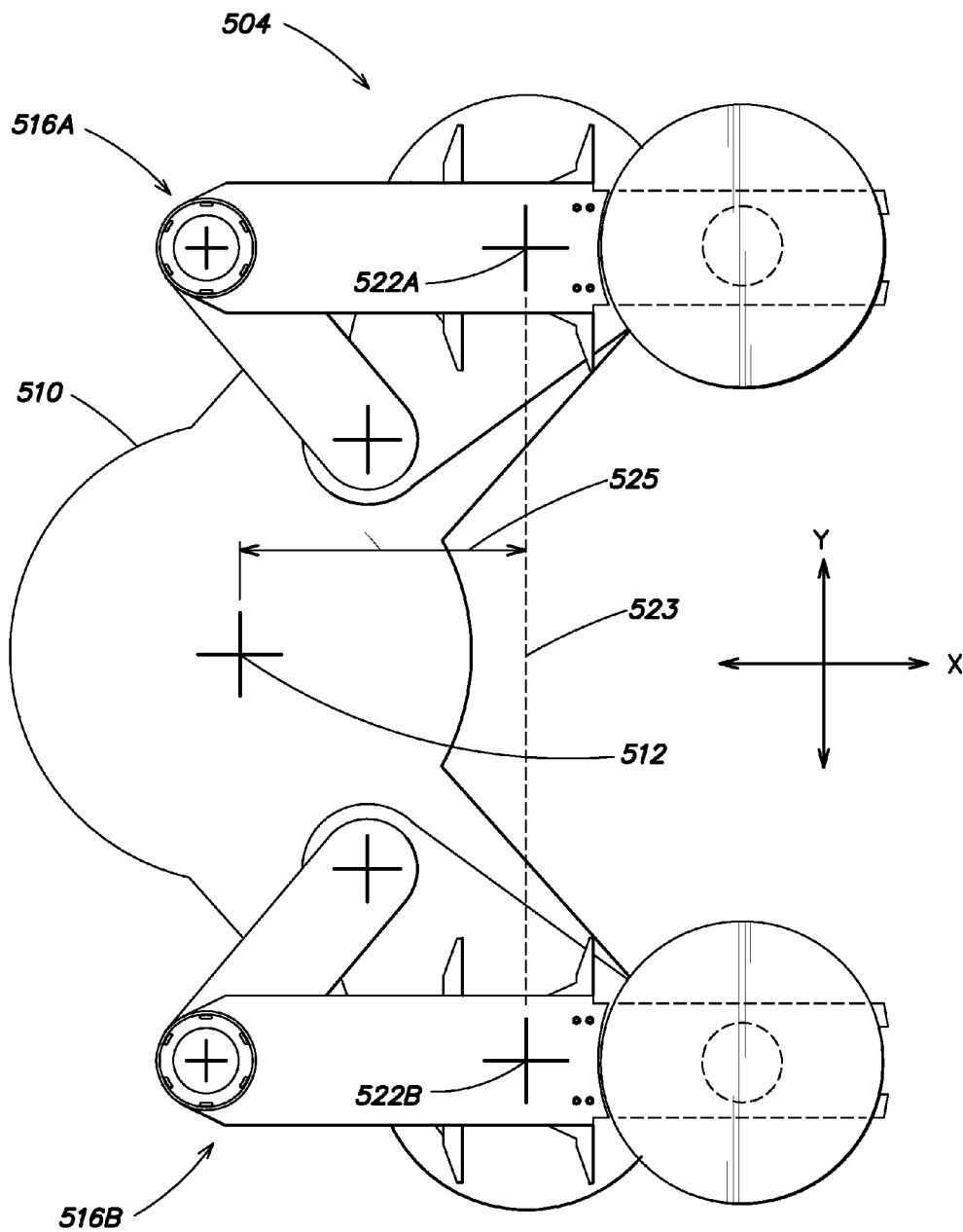
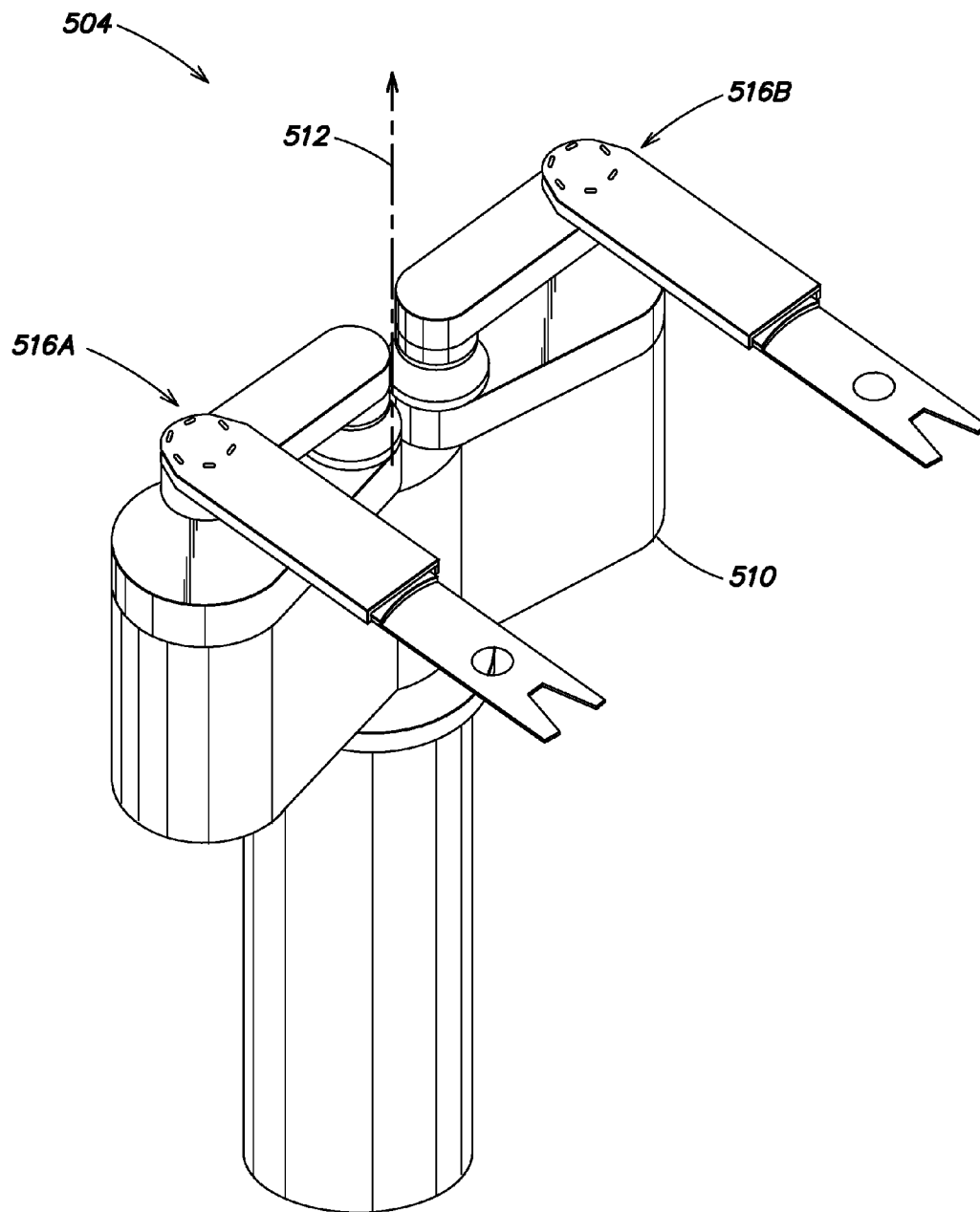


FIG. 5A



**FIG. 5B**

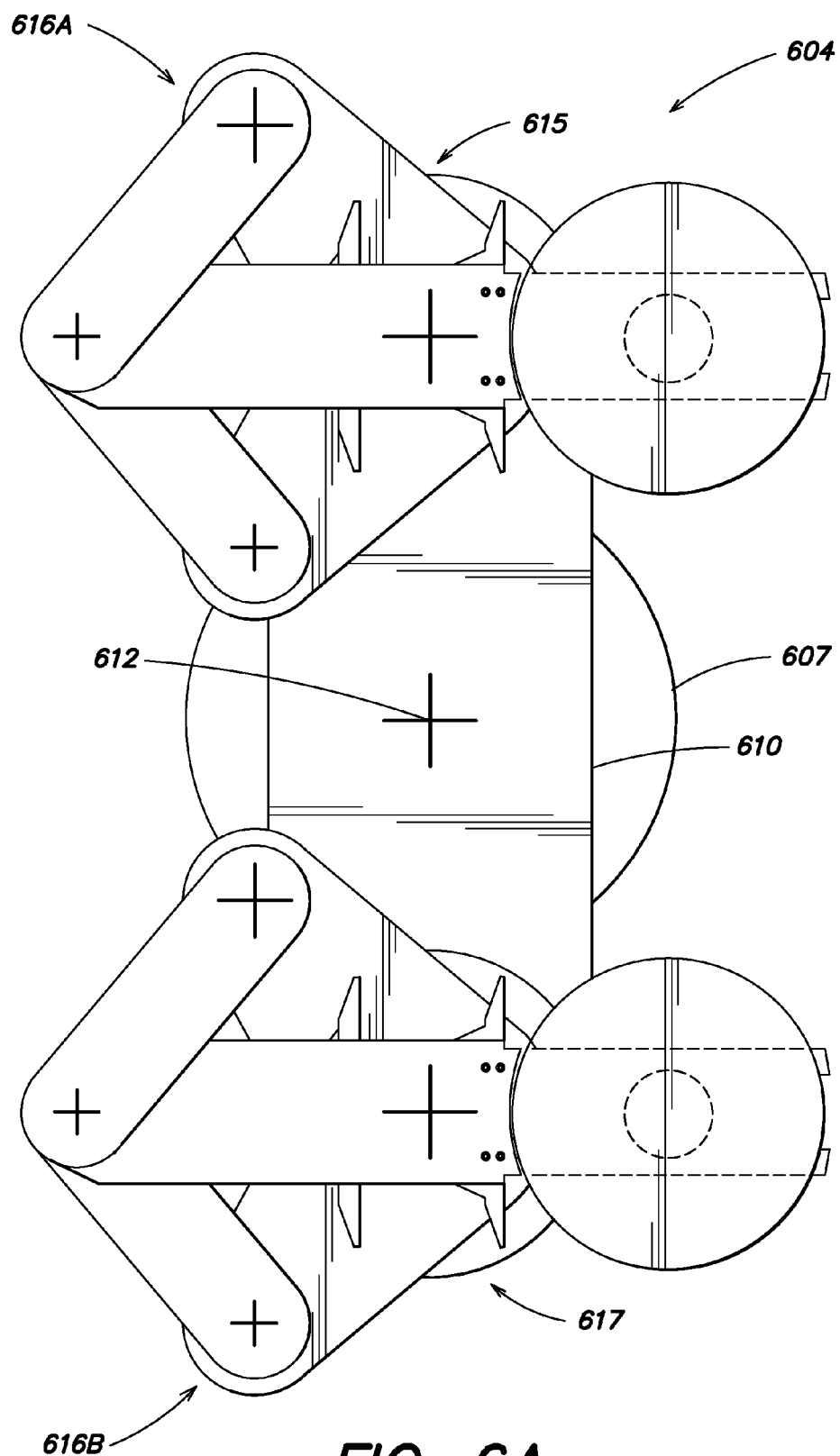


FIG. 6A

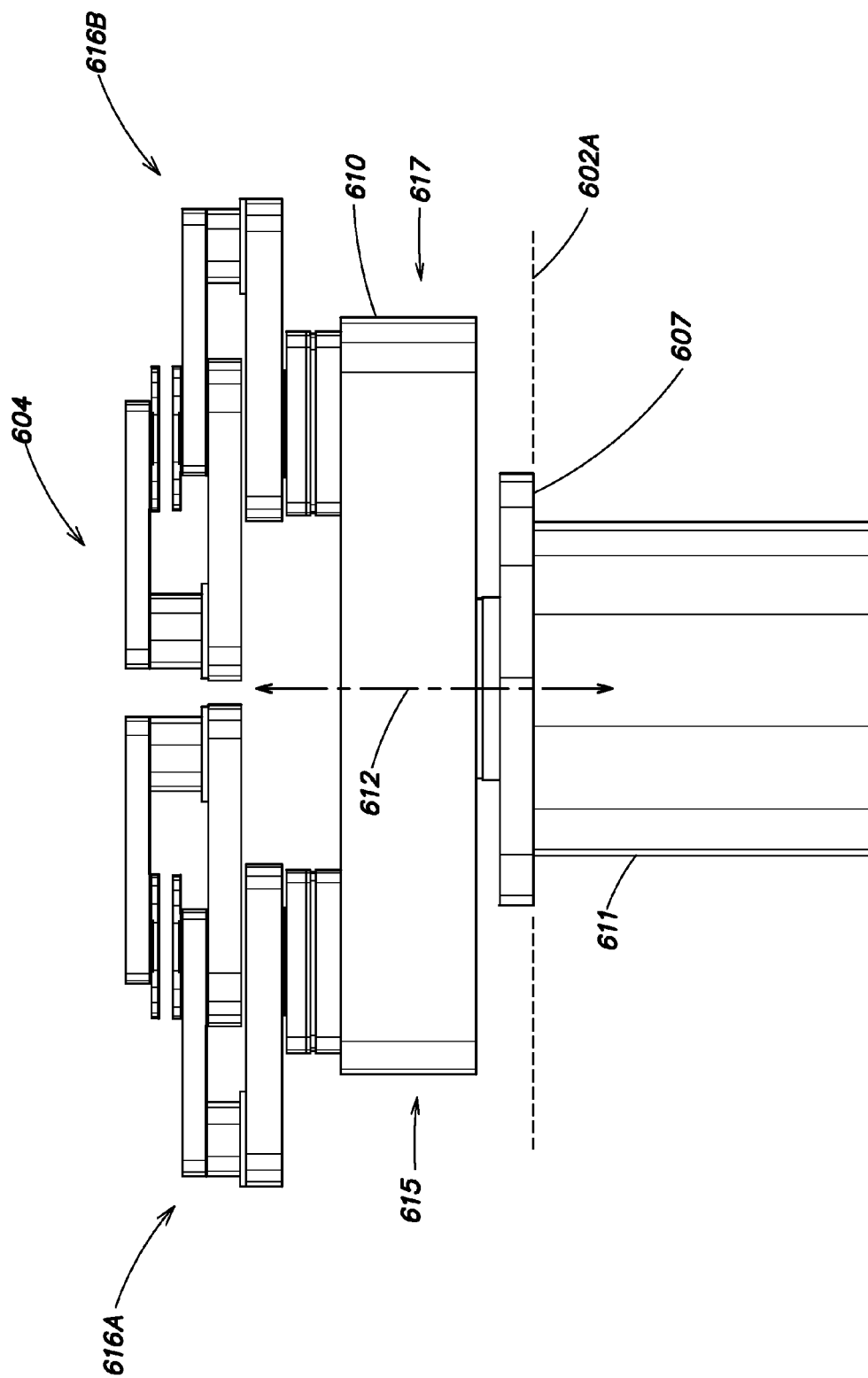
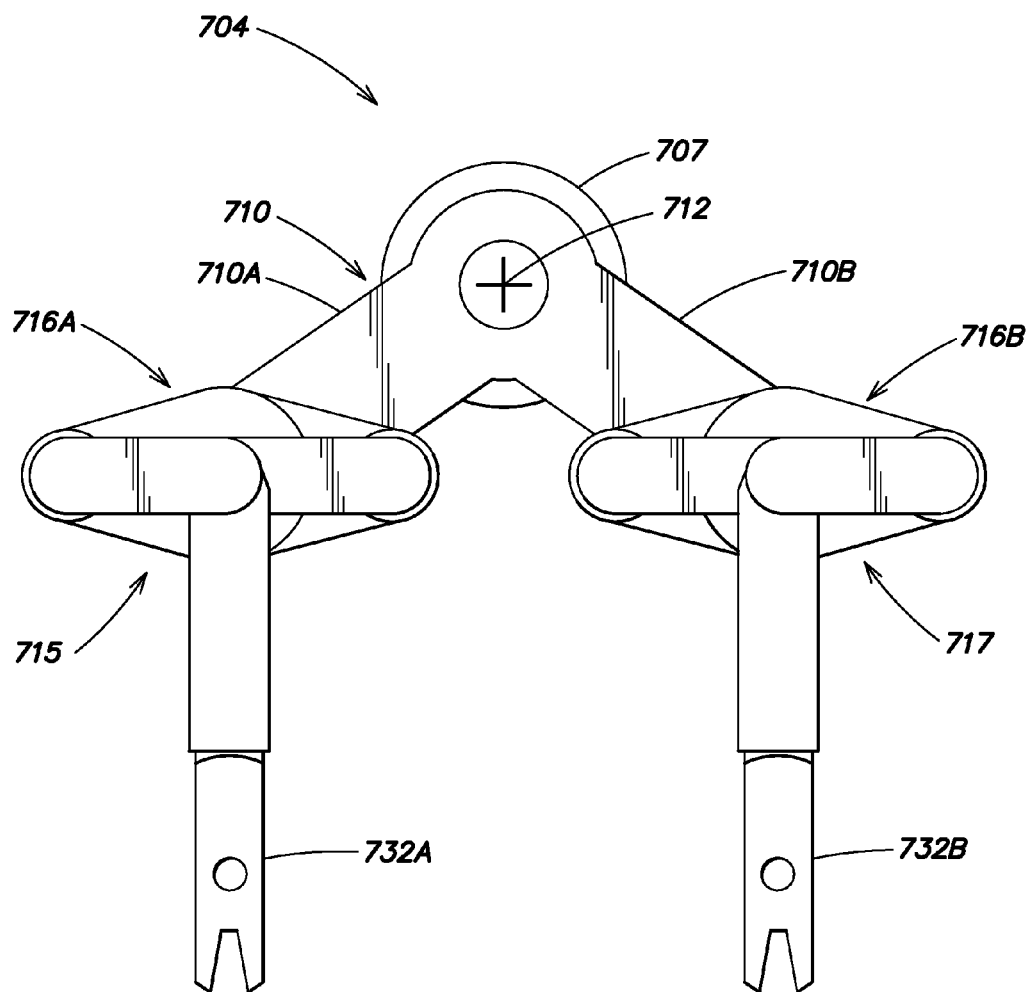


FIG. 6B



**FIG. 7A**



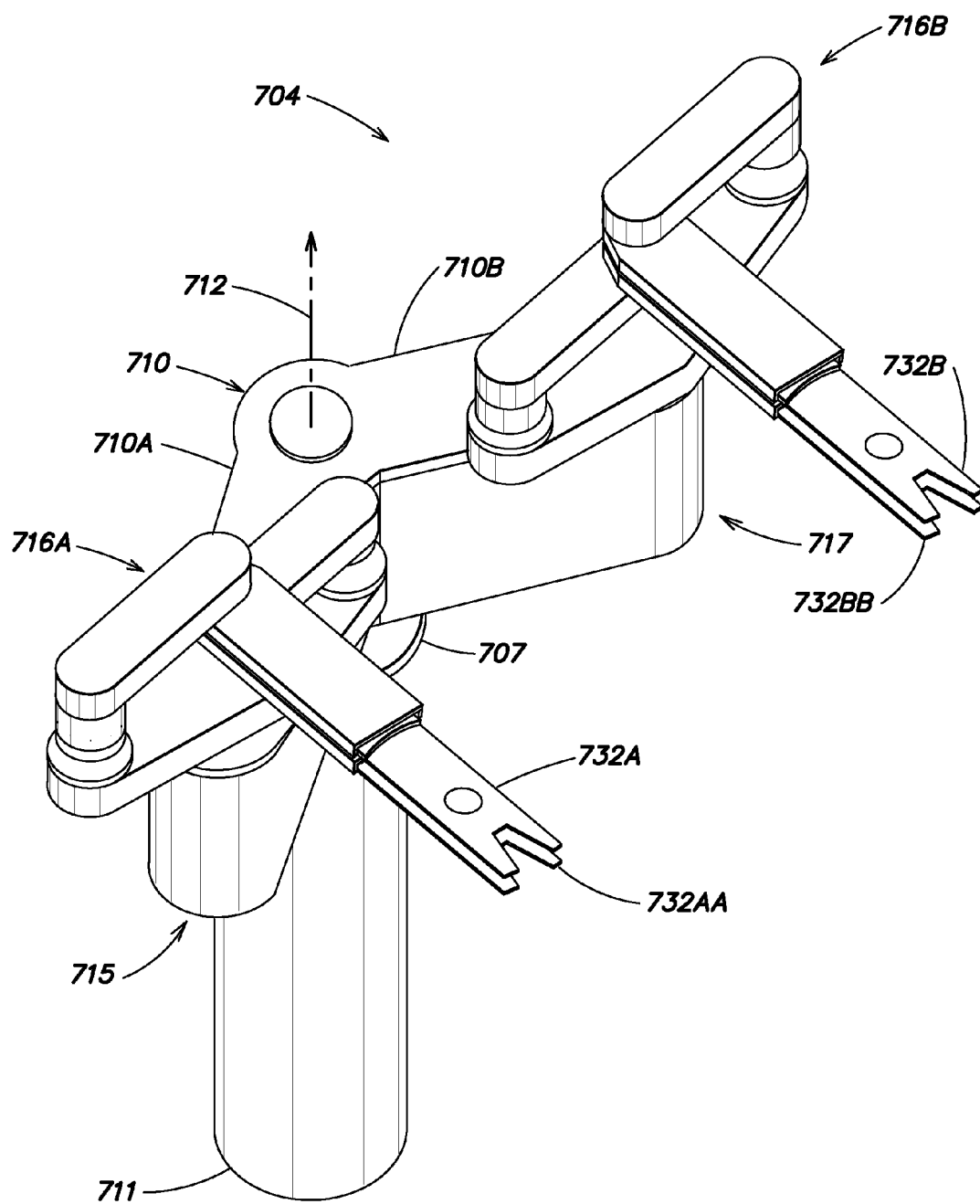


FIG. 7B

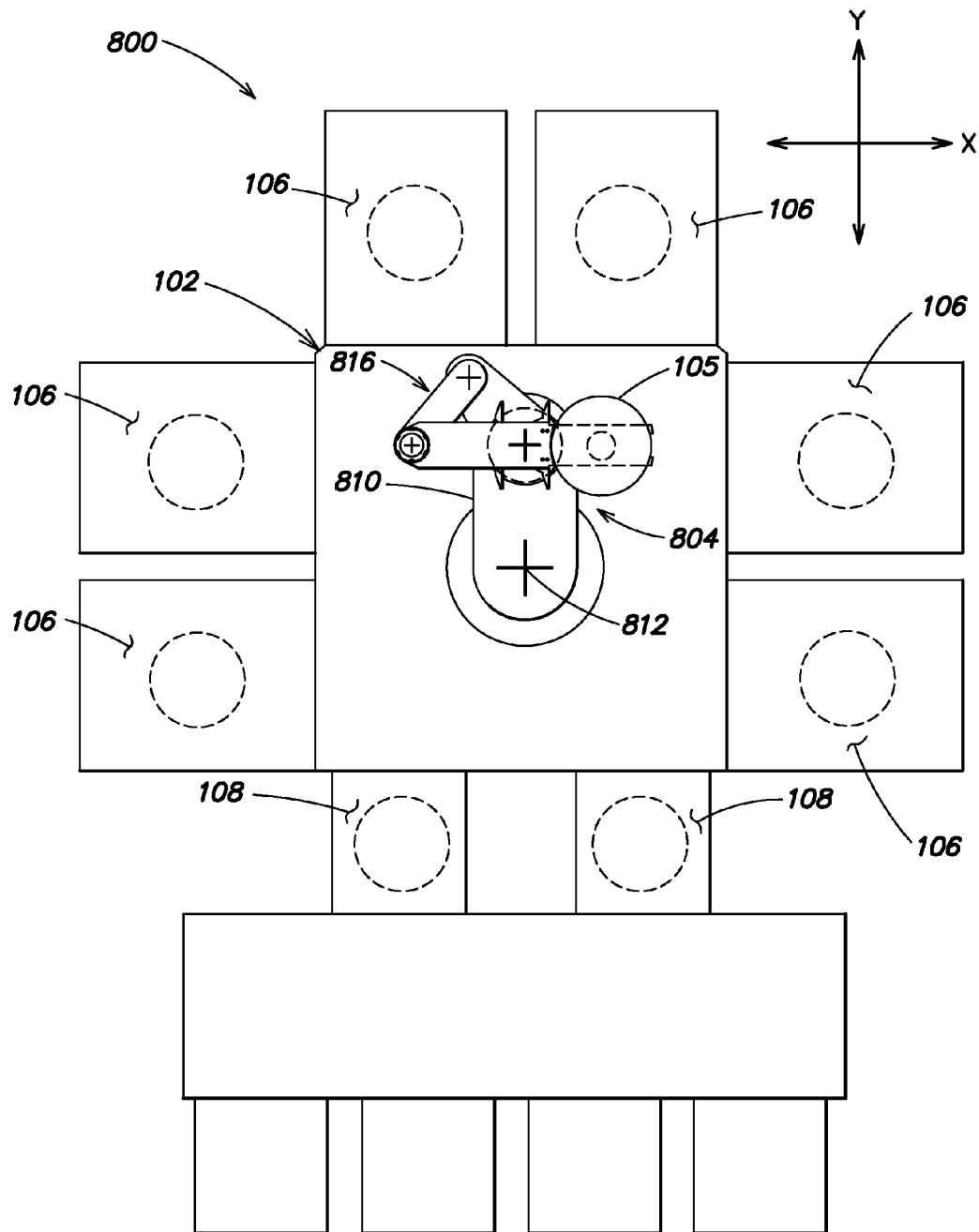
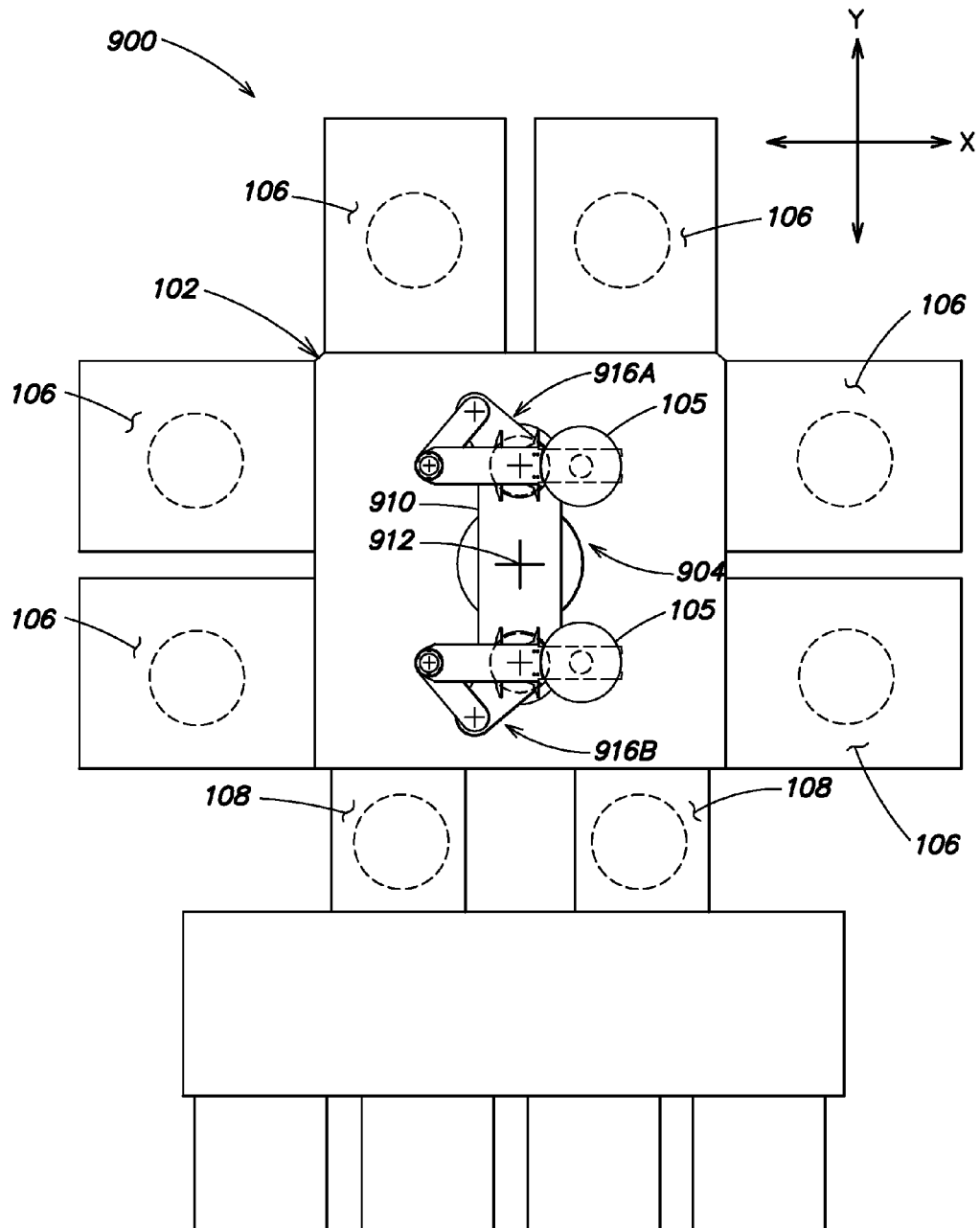
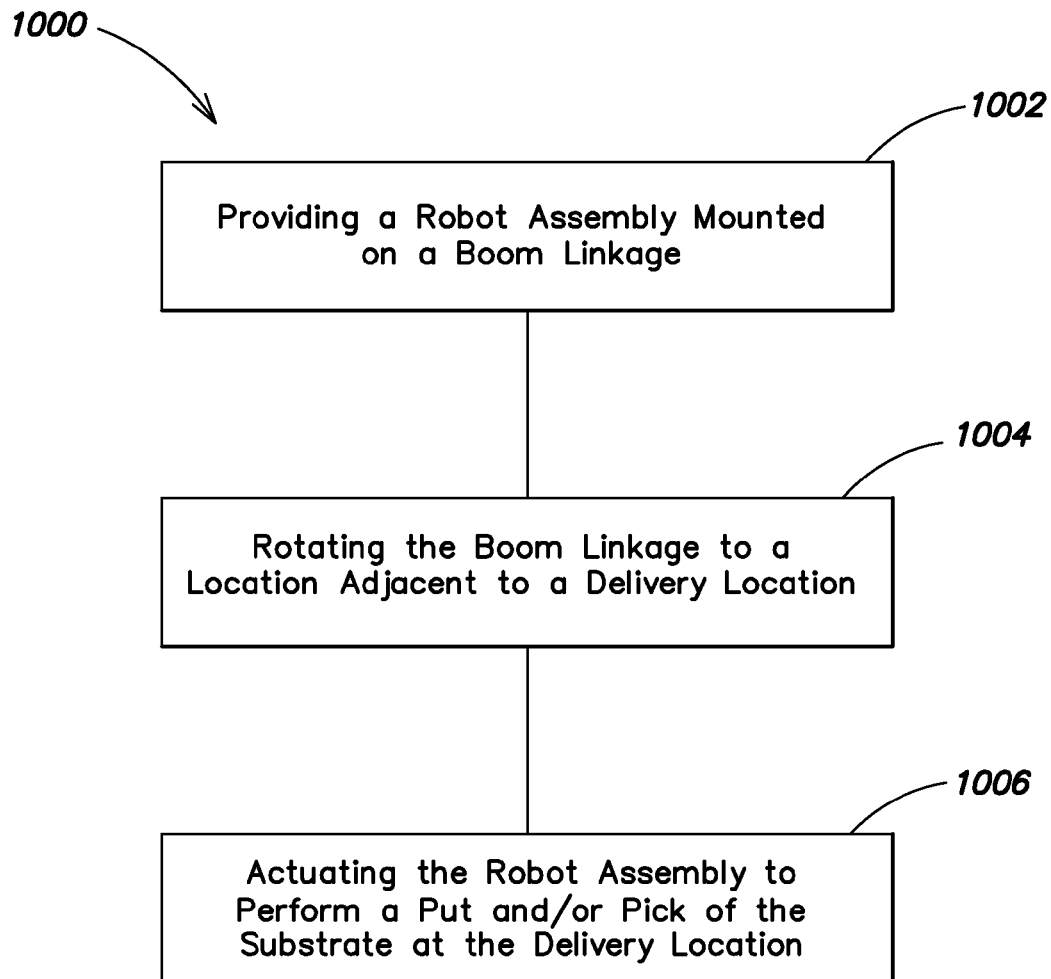
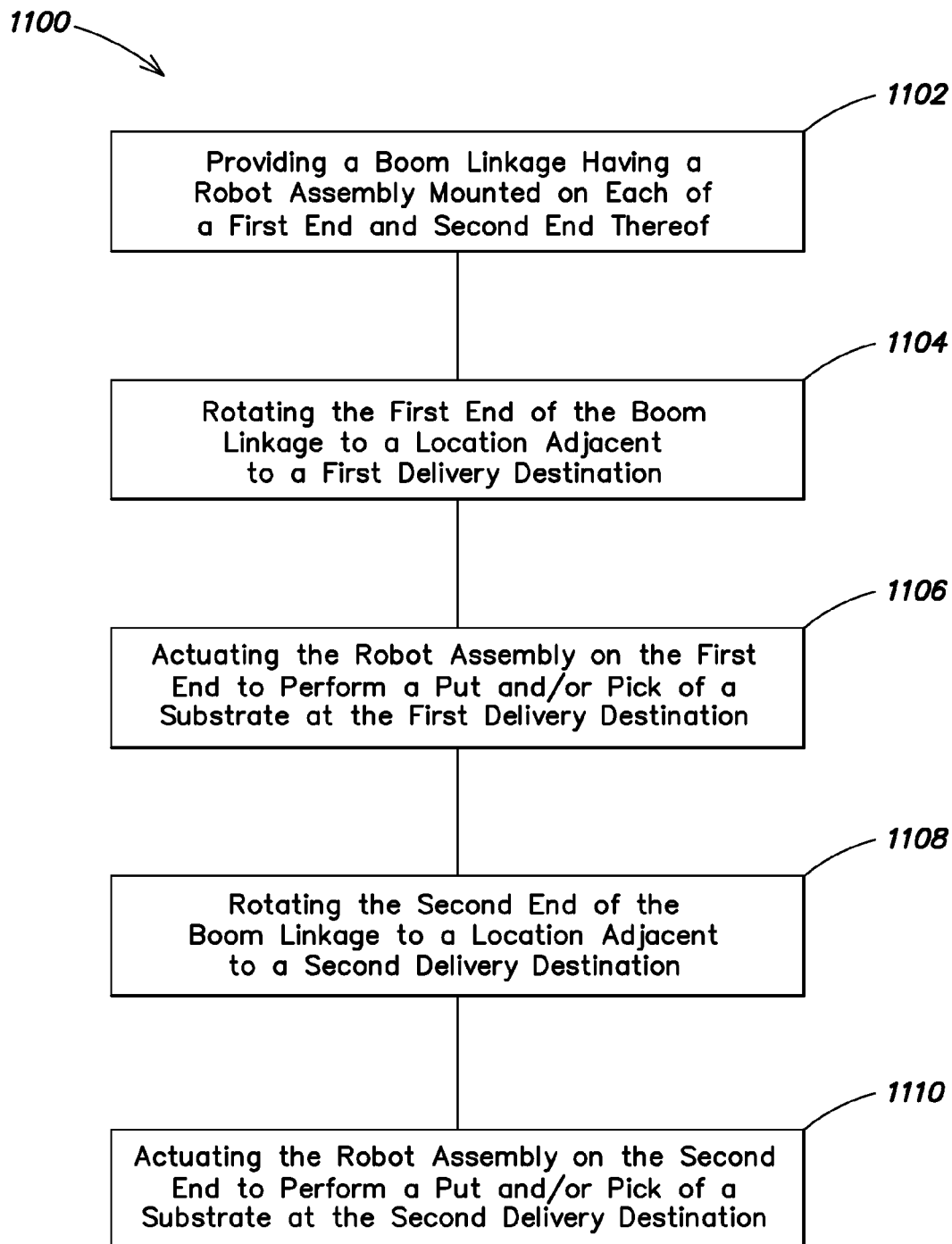


FIG. 8



**FIG. 9**

**FIG. 10**

**FIG. 11**

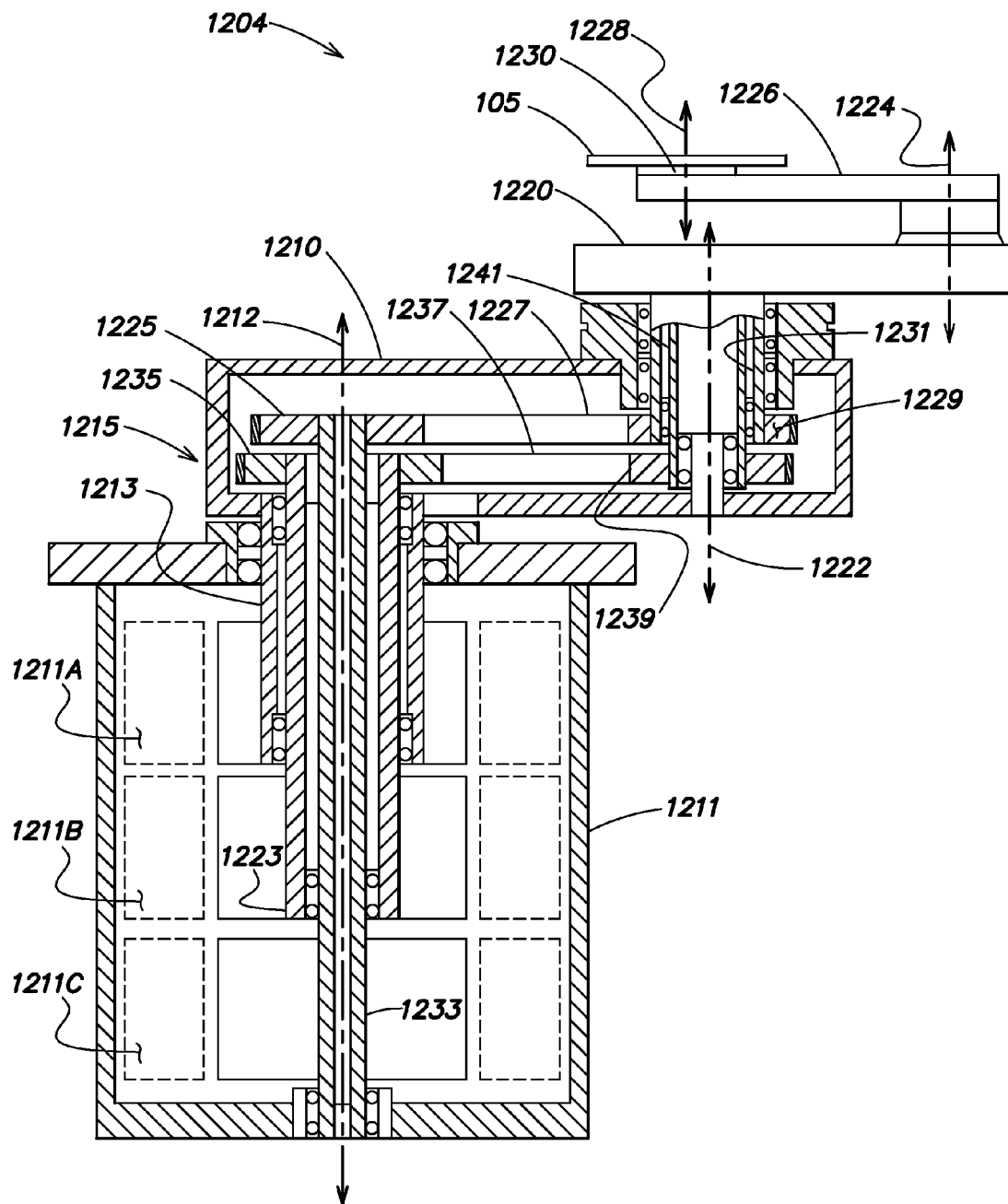


FIG. 12

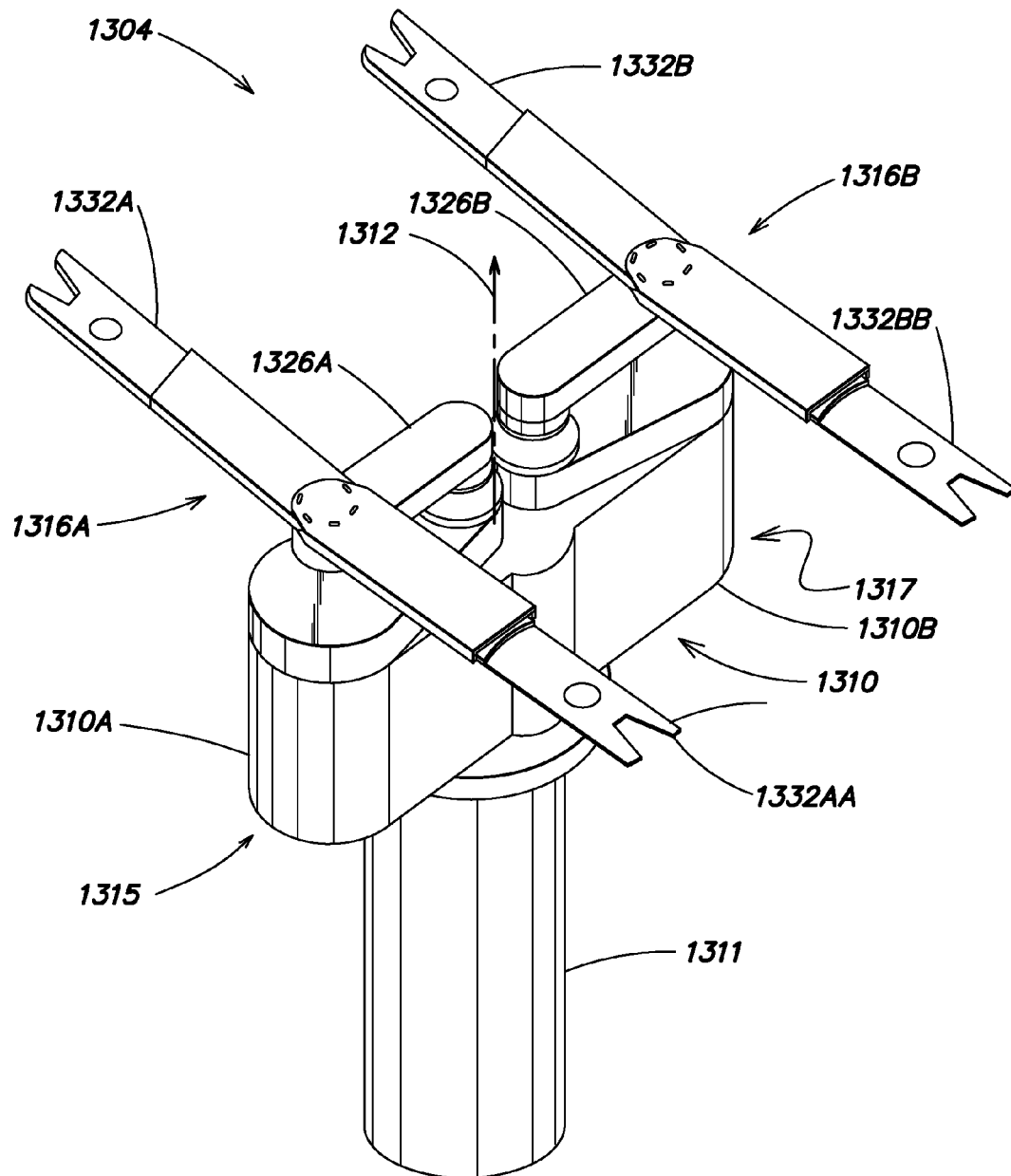
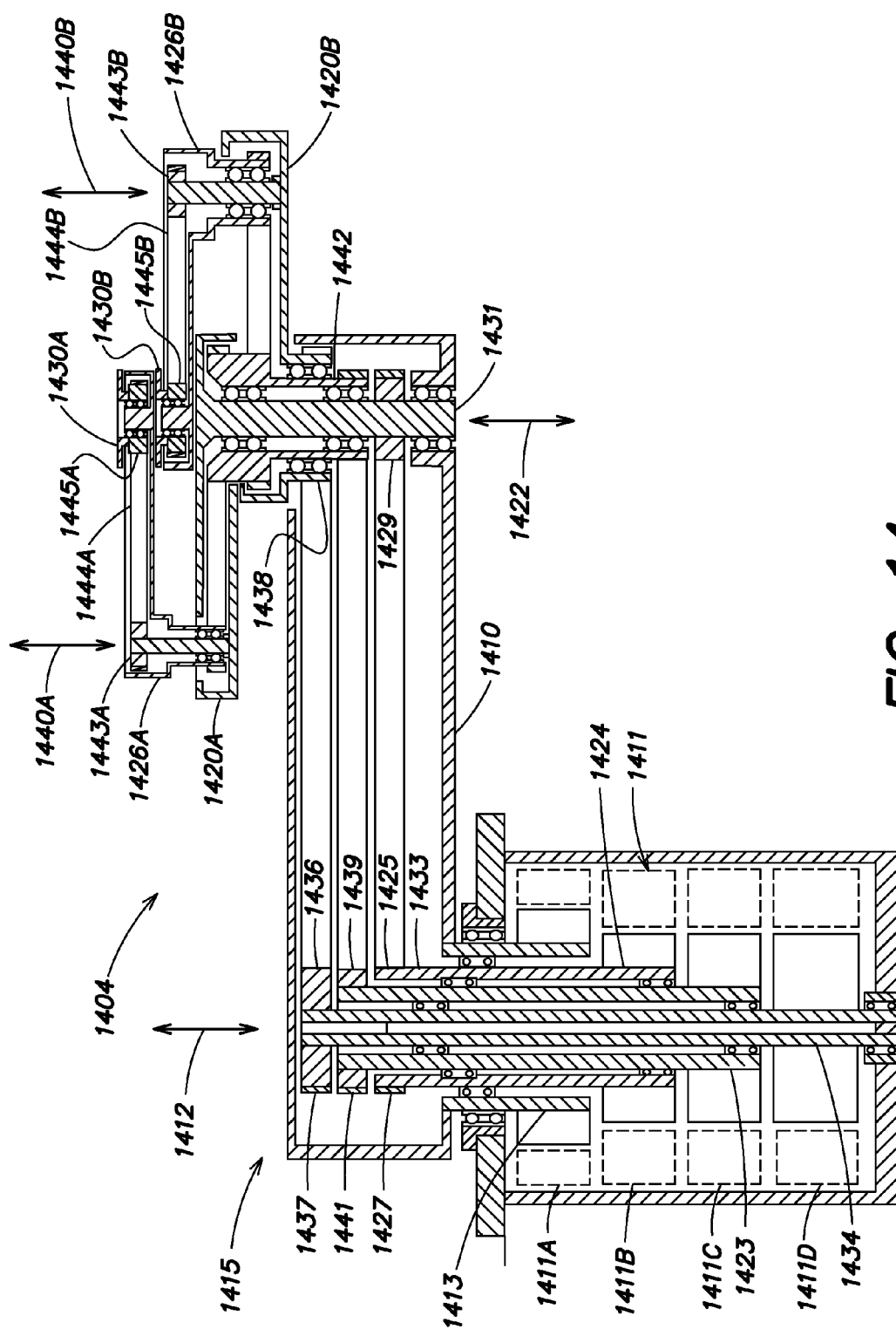


FIG. 13



**FIG. 14**



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## SUBSTRATE PROCESSING SYSTEMS AND ROBOT APPARATUS FOR TRANSPORTING SUBSTRATES IN ELECTRONIC DEVICE MANUFACTURING

The present application is a continuation application of, and claims priority to, U.S. patent application Ser. No. 12/684,780, filed Jan. 8, 2010, and entitled "ROBOTS SYSTEMS, APPARATUS AND METHODS FOR TRANSPORTING SUBSTRATES", and also claims priority to U.S. Provisional Patent Application No. 61/143,804, filed Jan. 11, 2009, and entitled "ROBOTS SYSTEMS, APPARATUS AND METHODS FOR TRANSPORTING SUBSTRATES IN ELECTRONIC DEVICE MANUFACTURING", each of which are hereby incorporated herein by reference in their entirety for all purposes.

### FIELD

The present invention relates to electronic device manufacturing, and more specifically to systems, apparatus and methods for transporting substrates.

### BACKGROUND

Conventional electronic device manufacturing systems may include multiple process chambers and load lock chambers. Such chambers may be included in cluster tools where a plurality of chambers may be provided about a transfer chamber, for example. These systems and tools may employ robots, which may be housed in the transfer chamber for example, to transport substrates between the various chambers and load locks. For example, the robots may transport a substrate from chamber to chamber, from load lock to chamber, and from chamber to load lock. Efficient and precise transport of substrates between the various system chambers may be important to system throughput, thereby lowering overall operating costs.

Accordingly, systems, apparatus and methods for efficient and precise movement of substrates are desired.

### SUMMARY

In one aspect a robot apparatus is provided. The robot apparatus includes a boom linkage adapted to be rotated about a rotational axis, the boom linkage includes a first cantilever beam and a second cantilever beam extending in two directions from the rotational axis; one and only one first robot assembly mounted to the first cantilever beam at a first shoulder axis, the first robot assembly including: a first upper arm mounted for rotation on the boom linkage about the first shoulder axis, the first upper arm extending inwardly from the first shoulder axis towards the rotational axis of the boom linkage, a first forearm coupled to an outboard end of the first upper arm, a first wrist member coupled to an outboard end of the first forearm, and a first end effector included on the first wrist member; and one and only one second robot assembly mounted to the second cantilever beam at a second shoulder axis, the second robot assembly including: a second upper arm mounted for rotation on the boom linkage about the second shoulder axis, the second upper arm extending inwardly from the second shoulder axis towards the rotational axis of the boom linkage, a second forearm coupled to an outboard end of the second upper arm, a second wrist member coupled to an outboard end of the second forearm, and a second end effector included on the second wrist member.

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In another aspect, a substrate processing system is provided. The substrate processing system In another aspect, a method of transporting a substrate within an electronic device processing system is provided. The substrate processing system includes a transfer chamber including first, second, third, and fourth walls, first, second and third walls including two process chambers each, and the fourth wall includes two load lock chambers; and a robot apparatus housed within the transfer chamber, comprising: a boom linkage adapted to be rotated about a rotational axis, the boom linkage includes a first cantilever beam and a second cantilever beam extending in two directions from the rotational axis; one and only one first robot assembly mounted to the first cantilever beam at a first shoulder axis, the first robot assembly including: a first upper arm mounted for rotation on the boom linkage about the first shoulder axis, the first upper arm extending inwardly from the first shoulder axis towards the rotational axis of the boom linkage, a first forearm coupled to an outboard end of the first upper arm, a first wrist member coupled to an outboard end of the first forearm, and a first end effector included on the first wrist member; and one and only one second robot assembly mounted to the second cantilever beam at a second shoulder axis, the second robot assembly including: a second upper arm mounted for rotation on the boom linkage about the second shoulder axis, the second upper arm extending inwardly from the second shoulder axis towards the rotational axis of the boom linkage, a second forearm coupled to an outboard end of the second upper arm, a second wrist member coupled to an outboard end of the second forearm, and a second end effector included on the second wrist member.

Numerous other aspects are provided in accordance with these and other aspects of the invention. Other features and aspects of the present invention will become more fully apparent from the following detailed description, the appended claims and the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic top view of a substrate processing system including a robot apparatus adapted to transport substrates according to the present invention.

FIG. 2A is a schematic top view of an embodiment of a robot apparatus according to the present invention.

FIG. 2B is a schematic side view of an embodiment of a robot apparatus of FIG. 2A according to the present invention.

FIG. 2C is a schematic perspective view of an embodiment of a robot apparatus of FIG. 2A according to the present invention.

FIG. 3A is a schematic top view of another embodiment of a dual robot apparatus according to the present invention.

FIG. 3B is a schematic side view of an embodiment of a dual robot apparatus of FIG. 3A according to the present invention.

FIG. 3C is a schematic perspective view of an embodiment of a dual robot apparatus of FIG. 3A according to the present invention.

FIG. 4A is a schematic top view of an embodiment of a robot apparatus according to the present invention.

FIG. 4B is a schematic side view of an embodiment of a robot apparatus of FIG. 4A according to the present invention.

FIG. 5A is a schematic top view of an embodiment of a robot apparatus according to the present invention.

FIG. 5B is a schematic perspective view of an embodiment of a robot apparatus of FIG. 5A according to the present invention.

FIG. 6A is a schematic top view of an embodiment of a robot apparatus according to the present invention.

FIG. 6B is a schematic side view of an embodiment of a robot apparatus of FIG. 6A according to the present invention.

FIG. 7A is a schematic top view of an embodiment of a dual robot apparatus according to the present invention.

FIG. 7B is a schematic perspective view of an embodiment of a robot apparatus of FIG. 7A according to the present invention.

FIG. 8 is a schematic top view of another embodiment of a substrate processing system including a robot apparatus of FIG. 2A according to the present invention.

FIG. 9 is a schematic top view of another embodiment of a substrate processing system including a robot apparatus of FIG. 4A according to the present invention.

FIG. 10 is a flowchart depicting a method of operating a robot apparatus according to embodiments of the present invention.

FIG. 11 is a flowchart depicting a method of operating a robot apparatus according to further embodiments of the present invention.

FIG. 12 is a partially cross-sectioned side view of a robot apparatus illustrating one possible drive system according to the present invention.

FIG. 13 is a perspective view of another robot apparatus illustrating dual end effectors according to the present invention.

FIG. 14 is a partially cross-sectioned side view of a robot apparatus illustrating another possible drive system adapted to drive a dual arm robot according to embodiments of the present invention.

### DETAILED DESCRIPTION

Electronic device manufacturing may require very precise and rapid transport of substrates between various locations. In particular, end effector apparatus may be attached at an end of an arm of a robot apparatus and be adapted to transport substrates resting upon the end effector to and from chambers of a substrate processing system. When the arms are long, rigidity of the robot mechanism may be a concern in that rapid starts and stops of the robot apparatus may cause vibration of the end effector. Accordingly, placement of the substrate may require waiting until the vibrations settle. In other words, settling time of the robot arms may be a concern.

One robot apparatus which may be used for transporting substrates between chambers in electronic device manufacturing according to an aspect of the invention includes boom linkage, which is adapted to be rotated to a location adjacent to a destination where a substrate is to be put or picked from the destination. A multi-arm robot including an upper arm, forearm, and wrist member having an end effector may be affixed to the boom linkage at a location spaced from a rotational axis of the boom linkage. The multi-arm robot is then actuated to accomplish the put or pick of the substrate to or from the destination. Thereafter, the boom may be rotated to a second destination where another put or pick may be carried out by the multi-arm robot. Accordingly, because the boom linkage may allow the robot assembly to be placed initially closer to the destination, the overall size of the arms of the multi-arm robot assembly may be made smaller thereby possibly reducing settling time.

Further details of example embodiments of the invention are described with reference to FIGS. 1-14.

FIG. 1 is a schematic diagram of an example embodiment of a substrate processing system 100 according to the present invention. The substrate processing system 100 may include a transfer chamber 102 within which a robot apparatus 104 in accordance with another aspect of the invention may be housed. The robot apparatus 104 may be adapted to put or pick a substrate 105 to or from a destination. The destination may be a chamber coupled to the transfer chamber 102. For example, the destination may be one or more process chambers 106 and/or one or more load lock chambers 108 which may be coupled to the transfer chamber 102. Process chambers 106 may be adapted to carry out any number of process steps, such as deposition, oxidation, nitration, etching, polishing, cleaning, lithography, or the like. The load lock chambers 108 may be adapted to interface with a factory interface 138, which may receive substrates from substrate carriers 140 docked in load ports 142. In some embodiments, the transfer chamber 102 may be operated under a vacuum, for example.

Now referring to FIG. 1 and FIGS. 2A-2C, the robot apparatus 104 may include a base 107 adapted to be attached to a wall 102A of the transfer chamber 102 wherein the wall 102A is shown dotted in FIG. 2B, a boom linkage 110, which, in the depicted embodiment, is a substantially rigid cantilever beam. The boom linkage 110 may be adapted to be rotated about a rotational axis 112 in either a clockwise or counterclockwise rotational direction. The rotation may be provided by any suitable motive power member 111, such as a conventional variable reluctance or permanent magnet electric motor. The rotation of the boom linkage 110 may be controlled by suitable commands to the motive power member 111 from a robot apparatus controller 119.

Mounted at an outboard end 114 of the boom linkage 110, at a position spaced from the rotational axis 112, is a robot assembly 116. The robot assembly 116 may be a three-link SCARA (selective compliance assembly robot arm) robot, for example. In operation, once the boom linkage 110 is positioned adjacent to the desired destination for a put or pick of a substrate, the robot assembly 116 may be actuated to put or pick a substrate 105 to or from the destination.

Now referring to FIGS. 2A-2C, a first embodiment of the robot apparatus 104 which may be adapted to be used in the substrate processing system 100 of FIG. 1 is described. As discussed above, the robot apparatus 104 may include a base 107, a boom linkage 110 rotatable relative to the base 107, and a robot assembly 116 which may be attached at an outboard end 114 of the boom linkage 110.

The robot assembly 116 may include a base 118 adapted to be attached to the boom linkage 110 and an upper arm 120, which may be adapted to be rotated in an X-Y plane relative to the base 118 and the boom linkage 110 about a shoulder axis 122. Coupled to the upper arm 120 at an elbow axis 124 located on an outboard end of the upper arm 120 may be a forearm 126. The elbow axis 124 is spaced from the shoulder axis 122. Furthermore, a wrist member 130 may be coupled to an outboard end of the forearm 126 at a wrist axis 128. The wrist axis 128 may be spaced from the elbow axis 124. The wrist member 130 may include an end effector 132 (shown partially dotted) which is adapted to carry the substrate 105 to be processed within the substrate processing system 100.

In the depicted embodiment of FIG. 1, the robot apparatus 104 is shown located and housed in a transfer chamber 102. However, it should be recognized that this embodiment of robot apparatus 104, as well as the other robot apparatus

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described herein, may be used in other areas of electronic device manufacturing, such as in a factory interface 138 wherein the robot apparatus may transport substrates or substrate carriers 140 between load ports 142 and load lock chambers 108 of the processing system, for example.

FIGS. 3A-3C illustrate another embodiment of a robot apparatus 304 that may be adapted for use within an electronic device processing system. The robot apparatus 304 in this embodiment may include a base 307 adapted to attach to a wall 302A (FIG. 3B) of a chamber, a boom linkage 310 which may be a rigid cantilever beam which may extend outward from a rotational axis 312 in a radial direction and which may be adapted for rotation about the rotational axis 312. The robot apparatus 304 may further include a dual robot assembly 316 including a dual set of arms mounted on the boom linkage 310 at an outboard end 314 spaced a distance from the rotational axis 312. In this embodiment, the robot assembly 316 may include two upper arms 320A, 320B each adapted for rotation about a shoulder axis 322. Each of the upper arms 320A, 320B may include elbow axes 324A, 324B located at their respective outboard ends and two forearms 326A, 326B may be coupled to the upper arms 320A, 320B at their respective elbow axes 324A, 324B. The forearms 326A, 326B may be adapted for rotation about their respective elbow axes 324A, 324B in the X-Y plane. The forearms 326A, 326B may each include a wrist axis 328A, 328B at their respective outboard ends at which two wrist members 330A, 330B may be coupled. The wrist members 330A, 330B are shown one overtop the other in FIG. 3A. The wrist members 330A, 330B may be adapted for rotation about their respective wrist axes 328A, 328B in an X-Y plane. End effectors 332A, 332B may be included on the wrist members 330A, 330B. The end effectors 332A, 332B may be attached to the wrist members 330A, 330B as a separate member or may be formed as an integral unit with the wrist members 330A, 330B. The end effectors 332A, 332B and substrates 105 carried by the end effectors 332A, 332B are shown one overtop the other in FIG. 3A. For clarity, the substrates 105 are not shown in FIG. 3C. Each of the boom linkage 310, upper arms 320A, 320B, forearms 326A, 326B, and wrist members 330A, 330B may be driven remotely by a motive power member 311, such as a variable reluctance or permanent magnet electric motor which may be included in a motor housing, for example.

FIGS. 4A-4B illustrate another embodiment of a robot apparatus 404 that may be adapted for use within an electronic device processing system. This robot apparatus 404 may be capable of servicing two chambers at once, for example. The robot apparatus 404 in this embodiment may include a centrally-located base 407 adapted to be attached to a wall 402A (FIG. 4B) of a chamber, such as a wall of a transfer chamber for example, and a boom linkage 410, which may include multiple rigid cantilever beams extending outward in opposite radial directions from a rotational axis 412. The boom linkage 410 may be adapted for rotation about the rotational axis 412 relative to the base 407 and may include robot assemblies 416A, 416B mounted at both a first end 415 and a second end 417 of the boom linkage 410 wherein each robot assembly 416A, 416B is spaced a distance from the rotational axis 412 wherein the first end 415 is opposite the second end 417 and spaced on opposite sides of the rotational axis 412.

In this embodiment, each robot assembly 416A, 416B may include an upper arm 420A, 420B adapted for rotation about their respective shoulder axes 422A, 422B in an X-Y plane. The upper arms 420A, 420B may include elbow axes 424A, 424B located at their respective outboard ends of the

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upper arms 420A, 420B, and two forearms 426A, 426B coupled to the upper arms 420A, 420B at their respective elbow axes 424A, 424B. The forearms 426A, 426B may each include wrist axes 428A, 428B at which wrist members 430A, 430B attach. The wrist members 430A, 430B are adapted for rotation about the wrist axes 428A, 428B in an X-Y plane. End effectors 432A, 432B may be included on the wrist members 430A, 430B. The end effectors 432A, 432B may be attached to the wrist members 430A, 430B as a separate member or may be formed as an integral unit with the wrist members 430A, 430B. The end effectors 432A, 432B may each be adapted to carry a substrate 105. The boom linkage 410, the upper arms 420A, 420B, forearms 426A, 426B, and wrist members 430A, 430B may be driven remotely by a motive power member 411, such as a variable reluctance or permanent magnet electric motor, which may be included in a motor housing, for example.

FIGS. 5A and 5B illustrate another embodiment of a robot apparatus 504 that may be utilized within electronic device processing systems. The robot apparatus 504 of FIGS. 5A and 5B is the same as the embodiment described with reference to FIGS. 4A and 4B except that the boom linkage 510 includes cantilevered portions that may extend radially outward in the X-Y plane from a rotational axis 512, but do so such that a line 523, when viewed in top plan view, passing through the respective shoulder axes 522A, 522B of the respective robot assemblies 516A, 516B may be offset a distance 525 from the rotational axis 512. This configuration of the boom linkage 510 may be advantageous for use in nonfocalized substrate processing systems, such as the six process chamber system shown in FIG. 9, for example. Utilizing the boomerang-shaped boom linkage 510 allows the robot assemblies 516A, 516B to be moved even closer to the chambers they service. Accordingly, the robot arms may be made even shorter. In some embodiments, an included angle formed by connecting 604

axes 522A, 512 and 522B is less than 180 degrees, less than about 150 degrees, or even less than about 120 degrees.

FIGS. 6A and 6B illustrate yet another embodiment of a robot apparatus 604 that may be utilized within an electronic device processing system. As in the previous embodiments, the robot apparatus 604 may include a base 607 adapted to attach to a wall 602A (FIG. 6B) of a chamber, a boom linkage 610 which may include multiple cantilever beams extending outwardly in opposite radial directions from a rotational axis 612 of the boom linkage 610. The boom linkage 610 may be adapted for rotation about a rotational axis 612 relative to the base 607 and may include robot assemblies 616A, 616B mounted at both a first end 615 and a second end 617 of the boom linkage 610; each of the assemblies 616A, 616B are mounted at a position spaced a distance from the rotational axis 612. The robot assemblies 616A, 616B are the same dual robot assemblies that are described with reference to FIGS. 3A-3C and will not be repeated again herein. As in the previous embodiments, each of the boom linkage 610, and robot assemblies 616A, 616B may be driven remotely by a motive power member 611, such as a variable reluctance or permanent magnet electric motor which may be included in a motor housing, for example.

FIGS. 7A and 7B illustrate yet another embodiment of a robot apparatus 704 that may be utilized within an electronic device processing system. As in the previous embodiments, the apparatus 704 may include a base 707, a boom linkage 710, which may include multiple cantilever beams 710A, 710B extending outwardly in generally opposite radial directions from a rotational axis 712 of the boom linkage

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710. The boom linkage 710 may have a generally boomerang shape and may be adapted for rotation about the rotational axis 712. Robot assemblies 716A, 716B may be mounted at first end 715 and second end 717 of the boom linkage 710. The robot assemblies 716A, 716B may be the same dual robot assemblies that are described with reference to FIGS. 3A-3C and will not be described again herein.

As in the previous embodiments, each of the boom linkage 710 and robot assemblies 716A, 716B may be driven remotely by a motive power member 711, such as a variable reluctance or permanent magnet electric motor which may be included in a motor housing, for example. In particular, the boom linkage 710 and the robot assemblies 716A, 716B may be driven from outside of a chamber in which the boom linkage 710 and the robot assemblies 716A, 716B are housed. In this depicted embodiment, the boom linkage 710 may be advantageous for use in nonfocalized substrate processing systems, such as the six process chamber system shown in FIG. 9, for example. Utilizing the boomerang-shaped boom linkage 710 may allow the robot assemblies 716A, 716B to be moved very close to the chambers they service. With the dual robots apparatus, a complete substrate exchange may be made at a destination possibly without needing to rotate the boom linkage 710. However, given that the boom linkage 710 moves the robot assemblies 716A, 716B very close to the chambers being serviced, the overall size of the robot assemblies 716A, 716B may be made relatively smaller than in conventional systems.

Thus, in operation, the boom linkage 710 having a robot assembly 716A mounted at a first end 715 will be first rotated about the rotational axis 712 to place the first end 715 of the boom linkage 710 adjacent to a first destination, i.e., at a position where the robot assembly 716A may readily access the destination. The robot assembly 716A may then be actuated; first to pick a substrate from the destination with one end effector 732A of the robot assembly 716A, and then to place a substrate with the other end effector 732AA of the robot assembly 716A. After this, the second end 717 of the boom linkage 710 may be rotated adjacent to a second destination where the robot assembly 716B may carry out another complete substrate exchange with the end effectors 732B, 732BB at the second destination in the same manner as described for the first assembly 716A. Of course because of the offset in the boom linkage 710 in this embodiment, complete exchanges may not require any further rotation of the boom linkage 710 or possibly only a small amount of additional rotation. For example, the boom linkage 710 may be rotated to an intermediate location where both robot assemblies 716A, 716B may readily reach the two destinations for substrate exchanges. The exchanges may be carried out, either sequentially or simultaneously.

FIG. 8 is a schematic diagram of another example embodiment of a substrate processing system 800 according to the present invention. The substrate processing system 800 may include a transfer chamber 102 within which a robot apparatus 804 may be housed. The robot apparatus 804 may be adapted to put or pick a substrate 105 to or from a destination in the system 800. The destination may be a chamber coupled to the transfer chamber 102, for example, or within the chamber itself. For example, the destination may be one or more process chambers 106 and/or one or more load lock chambers 108 which may be coupled to the transfer chamber 102. In some embodiments, the transfer chamber 102 may be operated in a vacuum, for example. In operation, the boom linkage 810 of the apparatus 804 may be rotated by a suitable motive power member, such as an electric motor, in either the clockwise or counterclockwise

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direction about the rotational axis 812. This may position the boom linkage 810 adjacent to the destination such that the robot assembly 816 may readily put or pick a substrate 105 to or from a chamber, such as process chamber 106.

FIG. 9 is a schematic diagram of another example embodiment of a substrate processing system 900 according to the present invention. The substrate processing system 900 may include a transfer chamber 102 within which a robot apparatus 904 may be housed. The robot apparatus 904 may be the same as the robot apparatus 404 shown in FIGS. 4A-4B and the details of the robot apparatus 904 will not be repeated herein. The robot apparatus 904 may be adapted to put or pick a plurality of substrates 105 to and/or from multiple destinations. Moreover, the put or pick of the plurality of substrates 105 may occur sequentially or substantially at the same time. The destinations may be chambers coupled to the transfer chamber 102. For example, the destinations may be one or more process chambers 106 and/or one or more load lock chambers 108 which may be coupled to the transfer chamber 102. In some embodiments, the transfer chamber 102 may be operated in a vacuum, for example. In operation, the boom linkage 910 of the robot apparatus 904 may be rotated by a suitable motive power member (not shown), such as an electric motor, in either the clockwise or counterclockwise direction about the rotational axis 912. This may position each end of the boom linkage 910 adjacent to the destinations such that the robot assemblies 916A, 916B may readily put or pick substrates 105 to or from a chamber, such as process chamber 106. As should be recognized, any of the other embodiments of the robot apparatus described herein may be included in a substrate processing system as shown in FIGS. 1, 8 and 9.

A method 1000 of transporting a substrate within an electronic device processing system according to the present invention is provided in FIG. 10. The method 1000 may include providing a robot apparatus including a robot assembly mounted on a boom linkage in step 1002; rotating the boom linkage to a location adjacent to a delivery destination in step 1004; and actuating the robot assembly to perform at least one selected from a group consisting of a put of the substrate to the delivery destination, and a pick of the substrate from the delivery destination in step 1006. Of course, where a dual robot apparatus, such as shown in FIGS. 3A-3C, is mounted on the boom linkage, a put and a pick of a substrate may be accomplished at the destination. After the put and/or pick has been accomplished, the robot assembly may be retracted from the destination to a neutral location and the boom linkage may then be rotated to a second position adjacent to a second destination, such as another process chamber or a load lock chamber, for example, wherein the process of 1006 may be repeated. In some embodiments, the boom may be rotated further towards the destination during the forward actuation of the robot assembly to assist in the put or pick operation.

In the embodiments where the boom linkage includes two robot assemblies mounted thereon, such as shown in FIG. 9, a method as best described with reference to FIG. 11 may be employed. The method 1100 may include providing a robot apparatus including a robot assembly mounted on each of a first and a second end of a boom linkage in step 1102; rotating the first end of the boom linkage to a location adjacent to a first delivery destination in 1104; and actuating the robot assembly to perform at least one selected from a group consisting of a put of the substrate to the first delivery destination, and a pick of the substrate from the first delivery destination in 1006. After the put and/or pick has been accomplished at the first destination, the robot assembly

may be retracted from the first destination to a neutral location and the second end of the boom linkage may be rotated to a second position adjacent to a second destination in **1108**, such as adjacent to another process chamber or load lock chamber, for example. The robot assembly mounted to the second end may then be actuated to perform at least one selected from a group consisting of a put of the substrate to the second delivery destination, and a pick of the substrate from the second delivery destination in **1110**. Thereafter, the boom linkage may be rotated to another destination wherein the process of **1106** may be repeated.

FIG. **12** illustrates an example drive system **1215** for driving the various components of the robot apparatus **1204**. First, the drive system **1215** may include drive components adapted to rotate the boom linkage **1210** about the rotational axis **1212**. A pilot **1213** may extend from the boom linkage **1210** and may be supported by suitable bearings wherein the pilot **1213** is adapted to be rotated by a component motor **1211A** of a motive power member **1211** about the rotational axis **1212**. The motor component **1211A** may be an electrical motor including a rotor and stator, for example.

Further, the drive system **1215** may include drive components adapted to rotate the upper arm **1220** about the shoulder axis **1222**. The drive components may include a drive shaft **1233** coupled to a drive pulley **1225**, a metal belt **1227**, and a driven pulley **1229** coupled to the upper arm **1220** by a second pilot **1231**. Rotation of a motor component **1211C** causes rotation of the shaft **1233** and drive pulley **1225** and drives the driven pulley **1229** thereby rotating the pilot **1231** and attached upper arm **1220** about the shoulder axis **1222**. The motor component **1211C** may be an electrical motor including a rotor and stator, for example.

Similarly, the drive system **1215** may include drive components adapted to rotate the forearm **1226** about the elbow axis **1224**. The drive components may include a second drive shaft **1223** coupled to a second drive pulley **1235**, a metal belt **1237**, and a second driven pulley **1239** coupled to the forearm **1226** and the wrist member **1230** by a third shaft **1241**, which may be connected to conventional SCARA belts and pulleys located in the upper arm **1220** and forearm **1226**. Rotation of a motor component **1211B** causes rotation of the second drive shaft **1223** and drive pulley **1235** and drives the second driven pulley **1239** thereby rotating the third shaft **1241**. Rotation of the third shaft **1241** rotates the forearm **1226** about an elbow axis **1224** and also rotates the wrist member **1230** about a wrist axis **1228**. The motor component **1211B** may also be an electrical motor including a rotor and stator, for example. Suitable conventional rotational encoders (not shown) may be used to position the boom linkage **1210** and upper arm **1220** and forearm **1226** as desired. Additional nested shafts and pulleys may be added to drive robot apparatus with dual end effectors and dual robot apparatus. Further, independent rotation of the wrist member to provide independent yaw motion about wrist axis **1228** may be provided, as will be discussed further below.

As should be apparent, this drive system **1215** may be used to drive the robot apparatus **1204** of FIGS. **2A-2C**, and may be modified to drive the robot apparatus of the embodiment of FIGS. **4A-4B** and FIGS. **5A** and **5B**, via generating an exact mirror duplicate of the components described above and extending them to the left of the rotational axis **1212**. These mirrored components would couple the respective belts thereof to identical pulleys adjacent to the pulleys **1225** and **1235**. In this way, a single motor component such as **1211C** may cause the rotation of upper arm **1220** and a corresponding upperarm (in the opposite direction) attached

to a radial boom extension on the other end (e.g., **415**) of the boom. Similarly, motor component **1211B** may cause the rotation of forearm **1426** and rotation (in the opposite direction) of a corresponding forearm attached to the boom extension on the other end of the boom (e.g., **410**).

FIG. **13** illustrates yet another embodiment of a robot apparatus **1304** that may be utilized within an electronic device processing system. As in the previous embodiments, the robot apparatus **1304** may include a boom linkage **1310** which may include multiple cantilever beams **1310A**, **1310B** extending outwardly in opposite radial directions from a rotational axis **1312** of the boom linkage **1310**. The boom linkage **1310** may be adapted for rotation about the rotational axis **1312** and may include robot assemblies **1316A**, **1316B** mounted at both a first end **1315** and a second end **1317** of the boom linkage **1310**. The robot assemblies **1316A**, **1316B** are the same dual robot assemblies that are described with reference to FIGS. **4A-4B**, except that rather than one, two end effectors **1332A**, **1332AA** and **1332B** and **1332BB** may be attached to the respective forearms **1326A**, **1326B**. As in the previous embodiments, each of the boom linkage **1310**, and robot assemblies **1316A**, **1316B** may be driven remotely by a motive power member **1311**, such as a variable reluctance or permanent magnet electric motor which may be included in a motor housing, for example. As the forearm **1326B** is caused to rotate when picking and/or placing a substrate (not shown), the end effectors **1332B**, **1332BB** may remain in a fixed orientation relative to each other, i.e., they may remain aligned. Similarly, as forearm **1326A** is caused to rotate when picking and/or placing a substrate (not shown), the end effectors **1332A**, **1332AA** may remain in a fixed orientation relative to each other.

FIG. **14** illustrates an example drive system **1415** adapted to drive the various components of the robot apparatus **1404**. This type of drive system **1415** may be used with the embodiments described with reference to FIGS. **3A-3C**, **6A-6B**, and **7A-7B**, for example. In comparison with the drive system of FIG. **12**, an additional drive component and additional motor component are added. First, the drive system **1415** may include drive components adapted to rotate a boom linkage **1410** about the rotational axis **1412**. A pilot **1413** may extend from the boom linkage **1410** and may be supported by suitable bearings wherein the pilot **1413** is adapted to be rotated by a component motor **1411A** of a motive power member **1411** about the rotational axis **1412**. The motor component **1411A** may be an electrical motor including a rotor and stator, for example. However, any suitable motor may be used.

Furthermore, the drive system **1415** may include drive components adapted to rotate a first upper arm **1420A** about the shoulder axis **1422**. The drive components may include a drive shaft **1433** coupled to a drive pulley **1425**, a metal belt **1427**, and a driven pulley **1429** coupled to the first upper arm **1420A** by a second pilot **1431**. Rotation of a motor component **1411B** causes rotation of the shaft **1433** and drive pulley **1425** and drives the driven pulley **1429** thereby rotating the pilot **1431** and attached first upper arm **1420A** about the shoulder axis **1422**. The motor component **1411B** may be an electrical motor including a rotor and stator, for example. However, any suitable motor may be used.

Similar to the first upper arm **1420A**, the drive system **1415** may include drive components adapted to rotate a second upper arm **1420B** about the shoulder axis **1422**. The drive components may include a drive shaft **1434** coupled to a drive pulley **1436**, a metal belt **1437**, and a driven pulley **1438** coupled to the second upper arm **1420B**. Rotation of a motor component **1411D** causes rotation of the shaft **1434**

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and drive pulley 1436 and drives the driven pulley 1438 thereby rotating the second upper arm 1420B about the shoulder axis 1422. The motor component 1411D may be an electrical motor including a rotor and stator, for example. However, any suitable motor may be used.

Additionally, the drive system 1415 may include drive components adapted to rotate the first forearm 1426A and second forearm 1426B about the elbow axes 1440A, 1440B, respectively. The drive components may include a drive shaft 1423 coupled to a drive pulley 1239, a metal belt 1241, and a driven pulley 1442 coupled to the first forearm 1426A and the second forearm 1426B. Activation of the motor component 1411C may cause the forearms 1420A, 1420B to rotate in opposite directions relative to one another.

The wrist members 1230A, 1430B may be coupled to the first and second upper arms 1420A, 1420B, respectively, by drive pulleys 1443A, 1443B, metal belts 1444A, 1444B and driven pulleys 1445A, 1445B. Thus, the wrist members 1430A, 1430B are positioned one above another (such as shown in FIG. 3A-3C, and activation of the motor component 1411C causes rotation of the drive shaft 1423 and drive pulley 1439 and drives the driven pulley 1442 thereby rotating the forearms 1426A, 1426B. Accordingly, the wrist members 1430A, 1430B move in opposite directions in a translational mode into and out the plane of cross section shown. The motor component 1411C may also be an electrical motor including a rotor and stator, for example. However, any suitable motor may be used. Suitable conventional rotational encoders (not shown) may be used to position the boom linkage 1410 and upper arms 1420A, 1420B and forearms 1426A, 1426B as desired.

Any of the aforementioned assemblies may include additional capability of controlling yaw of the wrist members. U.S. Provisional Patent Application No. 61/143,808 which was co-filed as PCT Patent Application No. PCT/US2010/020477 with the present application and entitled "SYSTEMS, APPARATUS AND METHODS FOR TRANSPORTING SUBSTRATES IN ELECTRONIC DEVICE MANUFACTURING," describes drive systems adapted to provide independent rotation of a wrist member of a robot.

As should be apparent, this drive system 1415 may be used in the robot apparatus of FIGS. 3A-3C, but may be modified to drive the assemblies of the embodiment of FIGS. 6A and 6B and 7A and 7B, via generating an exact mirror duplicate of the components described above and extending them to the left of the rotational axis 1412. These mirrored components would couple the respective belts thereof to pulleys identical to the pulleys 1425, 1439, and 1436, which may be arranged adjacent to or part of these pulleys. In this way, a single motor component such as 1411D may cause the rotation of upper arm 1420B and a corresponding upper arm (in the opposite direction) attached to the boom extension on the other end of the boom (e.g., 610, 710). Similarly, motor component 1411B may cause the rotation of upper arm 1420A and rotation (in the opposite direction) of a corresponding upper arm attached to the cantilever beam 710A on the other end of the boom. Furthermore, rotation of a single motor component such as 1411C may cause the rotation of forearms 1426A, 1426B and corresponding forearms attached to the boom extension on the other end of the boom (e.g., 610, 710).

The foregoing description discloses only example embodiments of the invention. Modifications of the above-disclosed apparatus and methods which fall within the scope of the invention will be readily apparent to those of ordinary skill in the art.

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Accordingly, while the present invention has been disclosed in connection with example embodiments thereof, it should be understood that other embodiments may fall within the spirit and scope of the invention, as defined by the following claims.

The invention claimed is:

1. A robot apparatus, comprising:

a boom linkage adapted to be rotated about a rotational axis, the boom linkage includes a first cantilever beam and a second cantilever beam extending in two directions from the rotational axis;

one and only one first robot assembly mounted to the first cantilever beam at a first shoulder axis, the first robot assembly including:

a first upper arm mounted for rotation on the boom linkage about the first shoulder axis, the first upper arm extending inwardly from the first shoulder axis towards the rotational axis of the boom linkage,

a first forearm coupled to an outboard end of the first upper arm,

a first wrist member coupled to an outboard end of the first forearm, and

a first end effector included on the first wrist member; and

one and only one second robot assembly mounted to the second cantilever beam at a second shoulder axis, the second robot assembly including:

a second upper arm mounted for rotation on the boom linkage about the second shoulder axis, the second upper arm extending inwardly from the second shoulder axis towards the rotational axis of the boom linkage,

a second forearm coupled to an outboard end of the second upper arm,

a second wrist member coupled to an outboard end of the second forearm, and

a second end effector included on the second wrist member, wherein a line extending between the first shoulder axis of the first robot assembly and the second shoulder axis of the second robot assembly is offset from the rotational axis of the boom linkage and wherein the line, the substrate support location of the first end effector, and substrate support location of the second end effector are each positioned forward of the rotational axis.

2. The robot apparatus of claim 1, wherein the outboard end of the first upper arm mounted for rotation on the boom linkage about the first shoulder axis, and the outboard end of the second upper arm mounted for rotation on the boom linkage about the second shoulder axis extend towards each but do not contact one another.

3. The robot apparatus of claim 1, wherein the first forearm that is coupled to the outboard end of the first upper arm, and the second forearm that is coupled to the outboard end of the second upper arm extend away from one another.

4. The robot apparatus of claim 1, comprising a third end effector and a fourth end effector coupled to each of the first forearm and the second forearm, respectively.

5. The robot apparatus of claim 4, wherein the third end effector and the first end effector remain in a fixed orientation relative to one another, and the fourth end effector and the second end effector remain in a fixed orientation relative to one another.

6. A substrate processing system, comprising:

a transfer chamber including first, second, third, and fourth walls, first, second and third walls including two

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process chambers each, and the fourth wall includes two load lock chambers; and  
 a robot apparatus housed within the transfer chamber, comprising:  
 a boom linkage adapted to be rotated about a rotational axis, the boom linkage includes a first cantilever beam and a second cantilever beam extending in two directions from the rotational axis;  
 one and only one first robot assembly mounted to the first cantilever beam at a first shoulder axis, the first robot assembly including:  
 a first upper arm mounted for rotation on the boom linkage about the first shoulder axis, the first upper arm extending inwardly from the first shoulder axis towards the rotational axis of the boom linkage,  
 a first forearm coupled to an outboard end of the first upper arm,  
 a first wrist member coupled to an outboard end of the first forearm, and  
 a first end effector included on the first wrist member; and

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one and only one second robot assembly mounted to the second cantilever beam at a second shoulder axis, the second robot assembly including:  
 a second upper arm mounted for rotation on the boom linkage about the second shoulder axis, the second upper arm extending inwardly from the second shoulder axis towards the rotational axis of the boom linkage,  
 a second forearm coupled to an outboard end of the second upper arm,  
 a second wrist member coupled to an outboard end of the second forearm, and  
 a second end effector included on the second wrist member, wherein a line extending between the first shoulder axis of the first robot assembly and the second shoulder axis of the second robot assembly is offset from the rotational axis of the boom linkage and wherein the line, the substrate support location of the first end effector, and substrate support location of the second end effector are each positioned forward of the rotational axis.

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